ELECTRICITY

AS A

MOTIVE POWER.

BY

COUNT TH. DU MONCEL,

MEMBRE DE L'INSTITUT DE FRANCE;

AND

FRANK GERALDY,

INGENIEUR DES PONTS ET CHAUSSÉES.

TRANSLATED, AND EDITED WITH ADDITIONS,

BY

C. J. WHARTON,

ASSOC. SOC. OF TEL. ENGS. AND ELEC.

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PREFACE.

Count Du Moncel's work, 'L'Electricité comme Force Motrice,' has only quite recently been published in France; and although I was favoured by him with the rough proofs, in order that the translation should appear as soon as possible after the original, some little time necessarily elapsed; and although that time has been very short, it was necessary, before this present book went to press, that considerable modifications and additions should be made, in order that it should bring down to the present moment the history of all that has been done in the employment of electricity as a motive power, and the almost daily developments and improvements that are taking place.

If further proof were required, this would show how important and pressing a subject at the present moment is the transmission and distribution of power. Owing to the recent wonderful developments in the various applications of electricity, the question of utilizing for the benefit of mankind the vast powers of nature at present wasted has assumed a practical shape, and the number of recent experi-

ments, books, papers, lectures, &c., by eminent and learned scientists, shows what a great future is looked for by those who have made a study of the subject. But at the same time very little of the difficulties or the possibilities of that subject are appreciated by the general public, and it is to them that I trust the present work may be useful and instructive.

C. J. WHARTON.

8 AND 9, HOLBORN VIADUCT,
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ELECTRICITY

AS

A MOTIVE POWER.

INTRODUCTION.

MOTIVE POWER is the basis of most great industries; and from the earliest ages of the world, man has been endeavouring to discover its best and most economical source. For a long time this power was obtained from the muscular energy of man and beast, but it was understood that this might be better utilised, and it was thought that it might be more economically and more powerfully obtained from the elements of nature. The effects of gravity, of running water, and of the winds, were first enlisted, and machines were made, capable of transforming these natural actions into a circular movement, susceptible in its turn of being applied in a thousand different ways to the various requirements of arts and manufactures. But there is not always running water at command, the winds are very uncertain and changeable, and the attraction of gravity can only produce a profitable action when it can be in-

definitely continued, which can only be obtained from water falling from a height. The progress of human industry, besides, necessitated motors capable of being placed where their want was felt, and whose power could be developed in any proportion and at any time that might be required; in fact, that they should be entirely subservient to human will. This problem in past ages formed an incentive to inventors, and led to the search for perpetual motion, for which, even in these days, some illusionists still strive; but when it was understood that, in obtaining such a result, one of the great laws of nature (equilibrium) could not exist, healthy minds could only look to physical actions for the solution of the problem; and it was Denis Papin who opened the way by discovering the expansive power of steam, and himself constructed a motor founded on this principle. The history of this magnificent discovery is well known, and the immense resources which steam-engines have given us. To recount them would be to give the history of all modern industries. However, this source of motive power has not remained the only one to be employed; and now-a-days we see that engines founded on the expansive power of gas play an important part in small industries; and every day they tend to multiply: a clear proof that the subdivision of motive power has become the question of the day. From this point of view, however, the problem has been lately solved in a satisfactory manner by a new means, by the help of a physical agent from which it could scarcely have

been hoped for half a century ago, and which has recently revealed to us effects which one could then hardly have dared to conceive. When we reflect that now we are enabled to transport to almost any distance a force of several horse-power by a wire which could easily be passed through a keyhole without any visible movement or any change in its appearance, imagination itself is stupefied, and we ask ourselves if it is not magic! This, however, is what electromotors can do to-day. Thanks to them, natural forces, hitherto useless, can perform at a distance from the source, work which could not have been made use of on the spot. Position now means nothing, and we may demand a supply of power as we demand a supply of water or gas; the same fluid which gives us power can also give us light. What progress science has thus made in the course of a few years! Then electricity with great difficulty could develop only a few foot pounds of work; and now we work ploughs, enormous pumps, cranes, mechanical saws, planing machines, punching machines, drilling machines, and railways even! The last Exhibition showed these marvels.

The first attempts to obtain motive power from electricity were not successful. Many inventors spent large sums of money only to obtain insignificant results; and it was only when the reversibility of continuous current induction machines was tried, that an advantageous solution of the problem could be looked for. Till then we had no electric currents sufficiently powerful to obtain any appre-

ciable work. But when it was shown that with two dynamo machines coupled one to the other, we could receive from the one more than half the motive power expended in the other to produce the electricity, we might imagine that not only were we in possession of a system of transmission of power to a distance which could often be utilised very advantageously even under these conditions, but that the electromotive machines themselves were capable of furnishing a force much greater than was supposed by supplying them with sufficiently powerful currents. Up till then, in fact, we had never been able to produce in this manner a force reaching one horse-power, and the most perfect motors did not give more than one or two kilogrammetres of force, which was ridiculous when compared with the expense which they necessitated. We were also on a wrong track, for it was sought to increase the power by an exorbitant increase of the size of the electro-magnetic apparatus. Since the question has entered the new phase, it has been studied in a more serious manner, and small motors have been made which can now furnish appreciable and useful work. We will devote a chapter to these little motors, of which the best known types are those of Deprez, Trouvé, Griscom, &c.; but we must explain here that power of any magnitude can only be furnished by continuous-current dynamo-electric machines, such as those of Gramme and Siemens.

The causes which led to the failure of the early attempts were principally, that it was only sought

to utilise the direct attractive force, which is, as all know, extremely limited and almost the same for very large electro-magnets as for small ones; that the arrangements of the commutators were very favourable to the development of induced currents in the coils which acted in a contrary direction to the current transmitted; that magnetisation and demagnetisation took place sluggishly in electro-magnets of any size, and therefore only a small part of their magnetism could be utilised, becoming even hurtful when it was not required; that the direct attractions between magnet and armature tended to bend the supports, necessitating too great a separation between the parts for the best of the work to be obtained; and finally, that the commutators were damaged by sparking, especially of the extra currents. We shall have occasion presently to study the various means proposed to modify these different defects, but they were evidently insufficient, since good results were never obtained, and it was only when the new application was discovered that these obstacles were sufficiently surmounted to enable the machines to work smoothly. These considerations have pointed out to us the order that should be followed in this work, which we will divide into two parts, the one treating of the early phase of electromotors since their origin till the time when the action of induction was discovered, and the other treating of this second phase of the question, with everything relating to the researches and applications of practical motors, including the transmission of force and its distribution.

It has, however, seemed necessary, to enable the reader thoroughly to grasp the technical parts of the question, to give some preliminary ideas as to the electric means employed in such motors, and these ideas will be found in the next chapter.

Principles on which the Construction of Electromotors is founded.

All the effects of the electric fluid capable of giving an impulse to a body, or of developing an attractive or repelling force, may be mechanically combined so as to form an electric motor. Thus, the reciprocal effects of electric currents on each other, the action of currents on magnets, of magnets on currents, and of temporary magnets on non-magnetised bodies, may, if the electric force and the size of the parts subjected to the action be sufficiently increased, be utilised as electro-dynamic motors. It may be understood that, possessing in electricity a force which may be cut off at a moment's notice by simply disconnecting the current, very simple mechanism suffices to transform the impulse given by it into a continuous rotary movement. Of all these properties, however, electro-magnetic attractions and repulsions, and those of parallel currents in the same direction, as in solenoids, have been the most utilised, setting aside the reversibility of continuous current dynamo-electric machines, the theory of which has not yet been fully elucidated.

To obtain a rotary movement by electro-magnetic attractions it is sufficient, as is easily understood, to

cause a succession of impulses resulting from these attractions to act upon a movable axis, and to provide this axis with a commutator, which before each electro-magnetic action closes the circuit, and opens it after the effect is produced. This problem may be directly solved by attaching to an axis a series of armatures, arranged like the blades of a paddle-wheel round a non-magnetic circumference, and moving before a like number of electro-magnets fixed round this circumference; or, indirectly, by fitting to this axis a crank and connecting-rod capable of transforming into rotary movement the to-and-fro movement caused by the momentary attraction of one or more armatures to the poles of electro-magnets fixed before them. The effects may also be combined so that the reciprocal actions of the armatures and electro-magnets may give rise to two movable systems acting simultaneously on the same axis, and as this arrangement may be applied to all the electric or electro-magnetic properties of which we have spoken, we see that electromotors of very different patterns may be constructed, which may be classed under various heads; but before describing them, it will be well to give some details of the best form of the different parts entering into their construction, and we will first speak of electro-magnets and solenoids, which are the most important of these parts.

ELECTRO-MAGNETS AND THE CONDITIONS FOR THEIR BEST CONSTRUCTION.

Different kinds of Electro-magnets.—An electro-magnet is, properly speaking, only a bar of iron, surrounded by a coil of insulated wire wound in layers and constituting a sort of bobbin, to which has been given the name of magnetising bobbin. This bar being straight, as in Fig. 1, constitutes a bar electro-magnet; when bent, as in Fig. 2, it is called a horse-shoe magnet. But these latter electro-magnets may also be made of two iron bars of equal length connected by an iron cross bar, as shown in Figs. 3 and 4. The bars are then called the arms, and the magnetising bobbin, instead of

FIG. 1.

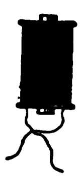


FIG. 2.

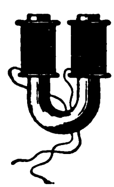


FIG. 3.

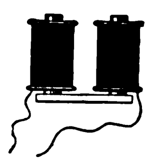
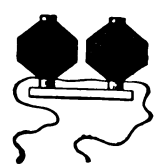


FIG. 4.



covering the whole magnetic system, is divided into two, and only covers the two arms. The parts covered by these bobbins are generally called the magnetic cores. Sometimes only one of the arms is covered with a bobbin, as in Figs. 5 and 6, and the electro-magnet is then called a one-legged electro-magnet. Sometimes several arms are placed on a single base, as in Figs. 7 and 9, thus making what

are called multipolar or consequent pole electro-magnets. In this case the poles are alternately of opposite signs. In other arrangements of electro-magnets with two poles the base is made circular,

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

and an iron cylinder fitted round it which envelops the arm on which the magnetising coil is wound, as in Fig. 8; this is called a tubular electro-magnet. In these conditions, one of the two poles forms a circular rim, in the centre of which is the other pole, and between them the magnetising coil. These

Fig. 9.

Fig. 10.

Fig. 11.

electro-magnets, as well as the others, may be cylindrical or oblong, as shown in Fig. 10; the latter are most used at the present day. Again, as in Fig. 11, the cylindrical covering is sometimes made

to cover only half of the bobbin, and another cylinder exactly similar, being fitted to the other half, forms a sort of cylindrical iron case with the iron core in the centre and containing the magnetising coil. This is a circular electro-magnet, and the poles are constituted by the two iron cylinders fixed to the two extremities of the core. They must, in consequence, be separated by a space of several millimetres at the middle of the bar. In this case the electro-magnet can revolve on its armature, always acting upon it by its two poles, which is sometimes very useful. This arrangement, first conceived by Nicklès, has often been made use of in electrical applications, and even in electromotors, as we shall see later. The preceding electro-magnet, deprived of the cylindrical covering and retaining only the iron rings where they are fastened, is called a circular electro-magnet with iron rings, and is often applied in the same cases as the other, if the armature is broad enough to unite the two rings. Some-

FIG. 12.

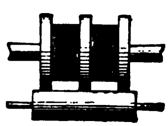
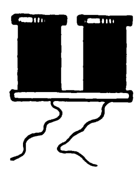


FIG. 13.



times instead of two rings there are three, as shown in Fig. 12. This arrangement has also been employed with advantage as a horse-shoe magnet, but then the rings act only as iron pole pieces. Fig. 13

is an electro-magnet of this description. There are also many other arrangements of electro-magnets, such as those in Figs. 14 and 15, by means of which circular plates are magnetised, as in Fig. 14, or so

FIG. 14.

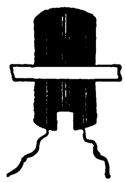


FIG. 15.

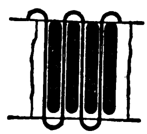
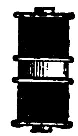


FIG. 16.



as to create north and south poles at different points of their surface, as in Fig. 15; but as these electro-magnets are little used, we will say no more about them now; we will only explain that all these electro-magnets may have their poles prolonged or fitted with iron pole pieces. We shall have occasion to speak of the advantages and disadvantages of these different forms, but we will first say a few words on the manner in which their armatures should be arranged.

The armature of an electro-magnet may be parallel or at an angle with the line joining the poles. In the first case it is sustained by rods or levers which work it parallel to this line. In the second case it is pivoted at one of its extremities so as to be very near one pole, and at a distance from the other. It may even be worked by a pivot on the nearer pole itself and constitute an expansion of this pole. We shall see directly that the electro-magnetic effects are infinitely stronger when the armature is acted

on by both poles than by only one, and this is why horse-shoe magnets are generally preferred; but the same advantages may be derived from a bar electro-magnet by bending the armature, and so arranging it as to be able to move before the two magnetic poles, as shown in Fig. 17. The same sort of attraction may also be obtained with a straight armature and a bar electro-magnet fitted with iron pole pieces.

FIG. 17.

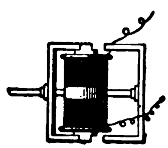
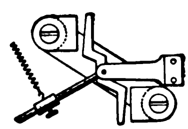


FIG. 18.



Lastly, an attractive action may be obtained by placing the armature between the two poles of an electro-magnet, so that the line of the poles and the axis of the armature pivoted in the centre form an X, as in Fig. 18.

But one of the arrangements most used in electro-motors is that based on the direct force of magnetic axes, which tends to set an armature moving parallel and tangential with the poles of an electro-magnet in a line coinciding with the polar axis, as will be seen in Fig. 19. A longer attractive stroke is thus obtained, but the action is not so powerful. This same action may be obtained with a straight armature pivoted between the poles of an electro-magnet, if these are enlarged and hollowed out, as shown in Fig. 20. Polarised armatures are often

employed; and as they would rapidly become demagnetised if they were made of steel bars magnetised, and as the attractive action is stronger with iron than with steel, they are polarised by putting

Fig. 19.

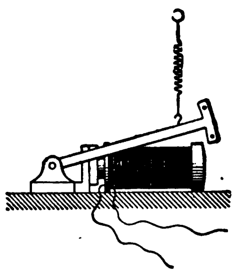
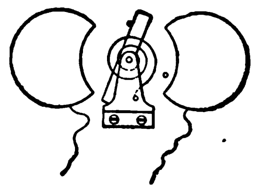


Fig. 20.

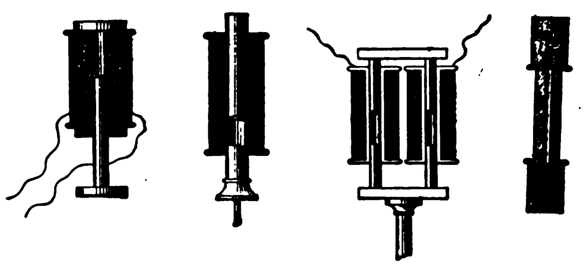


them in contact at one end with a powerful permanent magnet. Cecchi, Siemens, de Lafollye, d'Arlincourt, etc., have constructed some very ingenious magnets on this principle, which have been very largely employed in instruments of precision; but we only refer to them here in passing, as they have never been used for electromotors. The same may be said of Hughes's magnets, in which the iron cores, being fixed to the poles of a very powerful permanent magnet, are always magnetised, and only act when temporarily demagnetised by the action of their bobbins, thus being of very delicate action. Polarised armatures have also been used by making them of straight electro-magnets; but this means has seldom been applied except in telegraphy.

Solenoids.—Of all the properties of electric cur-

rents, that which has been most applied is the attraction exercised by a solenoid on a bar of iron fitting loosely inside the coils. Under the influence of the magnetic action developed in this bar by magnetisation, an attraction of parallel currents is produced between it and the coils of the solenoid or bobbin which tends to draw the bar into the bobbin until the two extremities of the bar correspond with those of the bobbin. By this means a considerable stroke is obtained, which may be still further increased by partitioning the bobbin, as Page and Marcel Deprez have done, and getting several successive actions. We shall notice later an important application of this arrangement.

FIG. 21. FIG. 22. FIG. 23. FIG. 24.



This action may be still further increased by adding iron rings to the two ends of the bobbin, as shown in Fig. 21, because the attraction of these rings is thus added to the action of the parallel currents.

By filling half the bobbin with an iron core, as in Fig. 22, it is made an electro-magnet, and its action,

added to the attraction of the solenoid in the first half of the bobbin, greatly increases the effect.

The same principle may also be adopted for two bobbins placed alongside one another, as shown in Fig. 23, when the electro-magnets become horse-shoe magnets, which increases the strength of the action. In Fig. 24 is represented an electro-magnet armature which consists of a bar electro-magnet with expanded flat poles capable of being fitted before the poles of an electro-magnet.

Bare Wire Electro-magnets.—For a long time it was thought that the coils of electro-magnets must be constructed of copper wire perfectly insulated with cotton or silk; but Carlier proved, in 1863, that those made of perfectly clean copper wire without covering were just as good; it was only necessary to be careful that the different layers should be well separated by pieces of paper. Good electro-magnets may be thus obtained which are as powerful as others when the current employed is not of very high tension, and they possess the advantage of furnishing no appreciable extra-currents. These electro-magnets are, however, somewhat difficult to construct. At the Electrical Exhibition of 1881, an American inventor, de Dion, exhibited electro-magnets of this description constructed with oxidised copper strips, which were remarkably powerful. We are surprised that constructors have not employed such electro-magnets to a greater extent.

Complex arrangements of Electro-magnets.—Besides the combinations of electro-magnets of which we

have just spoken, an attempt has been made to increase their power and rapidity of action by special arrangements of their armatures and magnetic core. Among these arrangements we will mention that in which the magnetic core is composed of cylindrical iron tubes one inside the other, each wound with magnetising coils of various thicknesses, the ends of all the coils being connected. These electro-magnets are then called multiple cored, and have been used in several different ways by Camacho and Cance, who have obtained very good results from them.

In Camacho's arrangement the cylindrical cores consist of iron tubes riveted to the cross-bar of the electro-magnet, and are four or five in number, besides a central solid iron core. The coils wound on these tubes are not generally very deep, except the outside one, in which there are more turns than in all the rest together. They are generally joined up in series, that is to say, so that the current goes through them all in succession. In Cance's arrangement these cylindrical cores consist of a large number of iron wires laid close together on and across each coil, which are pressed as closely as possible against the cross-bar so as to establish a magnetic contact between that and this iron covering. It will be understood that these electro-magnets are as easy to construct as ordinary ones, since these small rods of iron may be applied to the different layers in proportion to the length of wire wound upon them, and for this there is no necessity for the magnetising coil to be broken at each tubular core thus formed.

The advantage of these arrangements, from a scientific point of view, is that the residual magnetism is considerably diminished by the subdivision of the iron mass into a large number of diminutive individual magnets, which are much more rapidly magnetised and demagnetised than a single mass. They also exert a greater force in consequence of the mutual actions of the tubes on each other.

For the same reason armatures composed of thin iron plates are advantageous. Camacho and Chutaux have constructed electromotors on this principle, which were very successful in their time.

LAWS OF ELECTRO-MAGNETS.

The first data, a knowledge of which is necessary in considering electric motors, are the laws of electro-magnets, and they may be summed up as follows:—

1st. The force of an electro-magnet, or its magnetic moment, is proportional, for a given arrangement and circuit resistance, to the intensity of the current, and for a like electric intensity, to the number of turns in the magnetising coil. But when the electric intensity and the number of turns in the coil remain constant, the dimensions only of the electro-magnet being varied, this force is proportional to the square root of the diameter of the iron core and to the fourth root of its length; so that when all these quantities are variable together, the magnetic

moment is found when all the values are multiplied together.

2nd. The attractive force exerted between an electro-magnet and its armature by reason of their mutual action on each other is proportional to the squares of all the quantities just mentioned.

If the formulæ representing these values are examined mathematically, it will easily be seen that they are susceptible of maximum, and the conditions necessary in order to attain this maximum may be established: first, with reference to the resistance to be given to the magnetising coils; secondly, with regard to the proportion which should exist between the depth of the coils and the diameter of the core; thirdly, with reference to the length of the iron core: and these conditions of maximum may be stated in the following manner:—

1. For electro-magnets of the same dimensions having bobbins of the same diameter, the best sized wire for the coils is that which will give an equal resistance to that of the exterior circuit, at least when taking into consideration only the metal wire without its insulating covering.

2. If we take into consideration the thickness of this covering, the best coil is that of which the resistance will be to that of the exterior circuit as the diameter of the bare wire is to that of the same wire with its insulating covering.

3. Between several electro-magnetic bobbins wound with the same wire but having a different number of turns, that will furnish the best results

on a given circuit of resistance, of which the resistance is to the exterior circuit as the depth of the coils added to the diameter of the iron core is to that of the coils alone;

4. The best depth of coil for a given number of turns is that which equals the diameter of the magnetic core;

5. The most advantageous length for the magnetic core is eleven times its diameter; which means practically, that each arm of the electro-magnet should be six times the length of its diameter;

6. If there are branch circuits, the resistance of an electro-magnet introduced on one of these branches should equal the total resistance of the exterior circuit including the other branches taken inversely —that is to say, as if the electro-magnet and the battery had changed places;

7. The calculations that may be deduced from these various laws and the formulæ leading to them, enable us to establish the following principles, which are of great importance in electric applications:—

I.—For equal resistances of circuit, the diameter of an electro-magnet in maximum conditions must be proportional to the electromotive force of the battery employed.

II.—For equal electromotive forces this diameter must be in inverse proportion to the square root of the resistance of the circuit, including that of the battery.

III.—For equal diameters, the electromotive

forces must be proportional to the square roots of the resistance of the circuit.

IV.—For a given magnetic force, and with electro-magnets under maximum conditions, the electro-motive forces of the exciting batteries should be proportional to the square roots of the resistance of the circuit.

These laws have been demonstrated and proved in a small book published under the title of 'Determination des Eléments de Construction des Electro-aimants,' by M. Th. du Moncel.* They are, however, only true for electro-magnets attaining a suitable magnetic saturation. When this is not possible, either in consequence of their too great size or the shortness of time during which they are acted upon by the current, it is different; and the resistance of the magnetising coils should then always be less than that of the exterior circuit, in proportion to the length of time during which the current acts.

To apply these different laws to the construction of an electro-magnet, we first commence by finding out the diameter c of its magnetic core by means of the formula

$$c = \frac{E}{\sqrt{R}} \cdot 0159,$$

in which E represents the E. M. F. in volts of the battery, R the resistance of the exterior circuit in ohms; the figure obtained is in decimals of a metre. Knowing c, we at once have the length of each arm of the magnet, which is $6\,c$, or $12\,c$ for the two, and

* Translated and edited in English by C. J. Wharton.

the diameter of the wire of the helix is obtained by means of the formula

$$g = \sqrt{f\sqrt{\frac{c^2}{R}}\cdot 0000020106},$$

in which f is a coefficient which for electromotors is 1·4. It expresses the ratio existing between the diameter g of the covered wire and the diameter $\frac{g}{f}$ of the wire naked. The length H of this wire will then be given by the formula $\frac{75\cdot 4 \times c^3}{g^2}$, and the total number of turns by the formula $\frac{12 \times c^2}{g^2}$. All the numbers thus obtained are, as before mentioned, in metres or fractions of metres, with the exception of that referring to the number of turns of the wire, which, of course, is an abstract number.

Although in such an elementary work as the present algebraic formulæ should as much as possible be avoided, we have thought it better to give these very simple formulæ on account of the great assistance they might give to those going more deeply into the matter.

There are also a great number of data for the satisfactory construction of electro-magnets given in the work already mentioned, of which the following are the heads:—1st. The conditions of force in respect to exterior actions affecting the electro-magnetic organs. 2nd. The conditions of force in respect to the form and arrangement of the arma-

ture. 3rd. The conditions of force in respect to the mass of the magnetic core. 4th. The proper grouping of the cells of a battery in respect to a given exterior circuit and electro-magnet.

The conditions of force in respect to exterior actions tending to increase the power of a magnet may be summed up on this principle: that if the magnetic power of one of the poles of an electro-magnet is abnormally increased, either by the proximity or the contact of a mass of iron, the attractive power of the other pole is also greatly increased in proportion as this mass of iron is large and of considerable surface. It results, then, that a bar of iron, furnished at one extremity with a short coil, exercises at that pole a more powerful attractive force than if the same wire were wound on the whole length of the bar. This property may often be utilised in electric motors where straight electro-magnets are used, and explains why a magnet with two arms, and only one covered with a coil, is as powerful for a similar resistance of helix as an electro-magnet of similar dimensions having two coils.

The conditions of force in respect to the form and arrangement of the armature may be thus formulated:—

1st. The attractive force of any electro-magnet is greater in proportion as the surface of its armature, which directly receives the magnetic influence, is extended, as it is thus brought into better relation with the magnetic energy of the electro-magnet.

2nd. It follows that the attractive force of a horseshoe electro-magnet at a distance is greater with a prism-shaped armature placed lengthwise before the poles, than with the end presented, although the reverse is the case when the attractive force is exerted on contact. For an attraction at a distance the effects produced may be in the proportion of 59 to 92.

3rd. Armatures moving at an angle with the line of the poles of an electro-magnet, i. e. working on a joint near one of the poles, are much more effective than armatures moving parallel to this line or fitted cross-wise to a rocking lever. This advantage is especially noticeable with the one-legged electro-magnets, and the force varies in the proportion of 125 to 64.

4th. Prismatic armatures are attracted in proportion as the surface is extended, but the form of this surface has an immense influence on the attraction, on account of the mean distance of all the points which are under the influence of the magnet, which distance may vary very much with this form. Thus a cylindrical armature of the same surface as a square one is attracted with much less force than the latter, in the proportion of perhaps 85 to 44.

5th. In like manner the lateral attraction of an electro-magnet whose ends protrude a little beyond the bobbins is infinitely less than the normal attraction, i. e. that in line with the axis of the poles, in the proportion of 33 to 18.

6th. Armatures formed of permanent magnets do

not increase the attraction except at a distance, and when moving parallel to the line of the poles. In other cases the reverse obtains, as the magnetic action on steel is much less than on iron.

7th. The attractive force obtained by a momentary closing of the circuit for a similar distance is greater than that obtained by the same current continuously applied in the hope of overcoming the resistance. This is on account of the vis viva and of the effects of polarisation of the battery. The proportion of these forces is as 136 is to 95.

8th. When the attractive force of an electro-magnet is divided over several armatures, the total attractive force is increased, but the individual force of each is diminished in proportion to their number. This increase, however, is only shown up to a certain limit, which is attained when the mass of the armatures equals that of the electro-magnet.

9th. The attractive force of an electro-magnet and armature which have never been used is greater for a given electric force than that of the same magnet and armature after being strongly magnetised, and to obtain from the same magnet and armature a nearly equal force to that first obtained, the current must be reversed; still, this greater strength is then only to be found on first closing the circuit.

10th. The attraction at a distance is less, when from some cause the first closing of the circuit has not been followed by a complete attraction of the armature; this is explained, as also the preceding result, by the effect of the residual magnetism.

11th. The repulsive force developed by electro-magnets on a magnetised armature is very far from corresponding with the attractive force which may be obtained by reversing the poles of the magnet. This fact, recognised in the earliest researches on magnetism, and fully investigated by Mussembroeck and the Abbot Nollet, is explained by the fact of the magnet acting inductively, thus tending to develop in the armature a polarity opposite to itself. In attraction this influence increases the result, whereas in repulsion it has the contrary effect.

12th. When the iron cores protrude beyond the magnetising coils their strength is diminished, but if iron plates are fitted round the cores, the attractive force is increased, and the maximum effect is obtained when the distance between the two rings is about a quarter of the distance between the poles. This is occasioned by the greater attractive surface presented, which then nearly corresponds with that of the armature.

13th. According to the experiments of Dub, the best results are obtained when the different parts of the electro-magnet (arms of the magnet, breech, and armature) are equal in mass.

14th. This conclusion is of course subordinate to the conditions of application, for it is certain that if we wish to obtain a quick movement of the armature we must have a light one; but we may make up for it by providing the poles with iron rings.

The conditions of force of electro-magnets in respect to their mass may be summed up in this:

that the interior parts of the magnetic core are very often useless as regards their attraction, provided that they present the same exterior surface. Thus a magnet with tubular cores will be as powerful as one with solid cores, if the ends of the tubes are fitted with iron stoppers of the same thickness as the tubes. This thickness also depends on the electric force employed, for the depth of iron magnetised is greater the more powerful the current is.

As the residual magnetism is in proportion to the mass of the iron, great benefit is derived, if rapid magnetisation and demagnetisation is required, in using hollow cores with iron stoppers, and this advantage is the more marked in proportion as the interruptions of current are more rapid. This is why electro-magnets with multitubular cores are so advantageous, but in this case the iron stopper is not required and is even prejudicial.

The effects of residual magnetism must be distinguished from those of condensed magnetism; the former is occasioned by the impurity of the iron, which gives it a power of retaining its magnetism in the manner of permanent magnets. The latter is caused by a principle similar to that shown in the Leyden jar, i. e. that polarisation of the molecules, having been developed in conditions of equilibrium by means of the magnetising action, is maintained even after that action has been withdrawn, in consequence of the reciprocal effects of the opposite polarities in proximity to each other. It results from this, that on an electro-magnetic circuit being closed,

a part of the magnetism is hidden, and can only become free on the parts of the magnet being separated, or on opposite magnetisation being produced.

The actions of magnets may further be static or dynamic. They often act side by side, but sometimes in opposite directions. The effects of attraction are generally static, more or less nearly resembling electrical effects, and originate in an action which tends to displace the axes of the molecular polarities and set them in a state of equilibrium in respect to the effect produced. The magnetic poles are the centre of action. The dynamic effects are the properties excited in the magnetic solenoid, which, according to Ampère's theory, should cover the magnetised core like an electric spiral. The centre of this action corresponds with the neuter line of the core, and the effects produced are of similar nature to those caused by parallel currents through wire coils. Currents induced by magnets belong to this class, and express the external action of the magnetic current, which action may take place in all conducting bodies. It is the same with polar static action, but may differ according to the nature of the bodies which, according as they are magnetic or diamagnetic, are attracted or repelled.

The best arrangement of the cells of a battery to act on a given electro-magnet with a maximum result is obtained by calculations similar to those laid down for ascertaining the best conditions for the construction of the electro-magnets themselves, and

they may be summed up by saying that the battery should always be so arranged that its resistance should equal that of the electro-magnet or of the exterior circuit. If we take *b* as the number of cells arranged for quantity in each group, *a* for the number of groups joined up for tension, we shall find the number *b* of cells in each group by dividing the total resistance of all the cells of the battery *n* by 4, 9, 16, &c., successively, and finding which of the numbers thus obtained is the nearest to the given resistance of the exterior circuit. The figure of the corresponding divisor, whether 4, 9, or 16, indicates the square of the number of elements for quantity in each group, and the number of groups is obtained by dividing the total number *n* of the cells by that of those arranged for quantity in each group.

When the electric generator and the electro-magnet are undetermined, the useless resistance of the circuit settles what has to be done, and by useless resistance is meant that of the wires connecting the generator to the electro-magnet. If this is slight, as is the case with small electromotors used in private houses, it is eclipsed by that of the electro-magnet, and it may then be supposed to be connected by a wire thick enough to necessitate the grouping of the cells of the battery in parallel. The best arrangement for the battery may then be discovered by means of the directions given above; but if the useless resistance of the circuit is comparatively high, as great or greater than that of the cells

joined up for tension, no calculation is necessary, and the cells must always be joined up for tension.

This last arrangement of the battery is generally preferable, for the smaller quantity of electricity is compensated by a greater number of turns in the coils, and the battery is less quickly consumed. On the other hand, there is more to fear from the sparking of the extra current, and the commutators are more quickly deteriorated. This is evidently a question to be left to the judgment of the constructor, but the best way is to use wires of 1 to 2 millimetres in diameter for the electro-magnetic coils.

MEANS EMPLOYED TO DIMINISH THE DETRIMENTAL EFFECTS IN ELECTROMOTORS.

As we have already seen, the principal difficulties met with in the construction of electromotors are: 1st, the destructive effects of sparking on the commutators; 2nd, the short attractive distance of the electro-magnets; 3rd, the current induced by the motor which operates to the detriment of the useful currents; 4th, the residual magnetism which offers a resistance to the motion of the machine when it should be free; and 5th, the slow magnetisation of large electro-magnets, resulting in only their minimum force being usefully employed. Many ways have been proposed to overcome these difficulties, but were only very imperfectly successful till it was discovered that continuous current induction machines could be utilised as motors, which

being reversible, are pretty nearly perfect. The consideration of these latter machines will form, as we have said, the subject of the second part of this work, and we will here confine ourselves to the means used in the early electromotors.

Means employed to diminish the effects of Sparking on the Commutators.—To obtain from an electromagnet the alternate magnetisation and demagnetisation necessary to produce a mechanical effect, the electric current passing through it must necessarily be made and broken by means of a special arrangement, called a contact-breaker, or commutator, according as the effect is simple or accompanied by a reversal of the magnetisation. The question is considerably complicated by the introduction of electromagnets into a circuit, because of the induction spark resulting from the action of the turns one on the other, and the action of which is always more or less destructive to the metal strips making the contact with the commutators. In fact, however slight this sparking may be, it always in course of time oxidises the contacts and considerably increases the resistance of the circuit of the electro-magnet. If it is much, as is the case with currents of great intensity, not only the contacts are oxidised, but the metal of which they are composed is burnt and spoilt, and the commutator is soon rendered useless. Where contact is made by hand and the current of low intensity, it will be sufficient to clean the oxidised points of the commutator from time to time, and to bear forcibly upon it; but if the commutator is

worked by a mechanical contrivance driven by the electro-magnet itself, as in electromotors, it is quite another thing, and measures must be taken to avoid the disastrous effects which may follow.

To avoid these inconveniences many ways have been proposed, which may be considered from two points of view—that of the mitigation of the spark of the battery itself, and that of the sparking of the extra current arising from the intervention of the electro-magnet, which considerably increases the first by conjunction with it.

The earliest method employed to weaken the sparking of the battery was to divide the current on the commutator, and in consequence, instead of making the commutator of two single pieces of metal, a number are employed, connected to the conductor of the current by means of ramifications, which should have about the same resistance, so that the current does not pass more freely at one contact than at another. This plan, often employed by Froment, had also the advantage of furnishing better contact, for if one, from any cause, were bad, it would be more or less made up for by the others. It is this consideration which has for many years led to the use of brushes of metal wire, which are now employed in nearly all induction machines and electric motors.

Although, however, the direct sparking from the battery was thus weakened, this means was insufficient to destroy the effect of the extra current, and combinations which would solve the problem from

this point of view were sought. At one time there was an idea of introducing on a branch circuit a condenser of great extent, as had been done for the same purpose in the Ruhmkorff induction coil; then, returning to Ampère's primitive commutator, contact pieces were tried made of platinum amalgam and bars of platinum dipped in liquid of low conductivity, such as alcohol; but these methods, though suitable for induction machines like Ruhmkorff coils, were not satisfactory for electromotors, and it was necessary to discover a more satisfactory solution.

One of the most simple was employing electro-magnets with bare wire arranged on Carlier's plan, of which we spoke on page 15. In these electro-magnets the contact of the turns is imperfect enough, as we have seen, to impede, to a certain extent, the spreading of the voltaic current through the mass of the wire of the bobbins; but it is not enough so to obstruct the derivation of the extra-current, which is of higher tension, and this is, so to speak, cancelled by its closing on itself. We are surprised that this simple method is not more frequently employed, for it is very efficacious.

This plan of destroying the extra current has also been employed in another form, in the arrangement represented below, which was originally contrived in 1855 by Dering. Here the interruption of the current does not take place on the wire connecting the electro-magnets direct to the battery, but on a shunt joining the two ends. These electro-magnets must then be of high resistance, so that the current

dividing between the shunt circuit where the commutator is placed and that of the electro-magnet, passes more freely along the short branch circuit when it is closed by the commutator, than along that of the electro-magnet which offers more resistance. In Fig. 25 the electro-magnets are at C B, the branch circuit is G F E, and the battery at D A. When the eccentric part of the commutator F is presented to the contact spring, the current passes through the circuit A E F G D, while if the contact is broken at F it passes through the circuit A E B C G D; and as one or other of the circuits is always closed, the sparking becomes less dangerous.

Fig. 25.

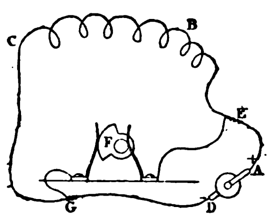
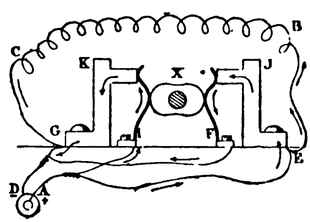


Fig. 26.



Although by this means the current passes almost completely through the branch circuit E G, yet a small portion nevertheless goes through the circuit E B C G and tends to reinforce the residual magnetism which is so detrimental to the mechanical properties of electro-magnets. To prevent this branching, the arrangement in Fig. 26 has been contrived, which is rather more complicated, and which acts as a real interruption to the current. An inspec-

tion of this figure will be sufficient to explain its mode of action. We must, however, say that all these plans are difficult to apply, because of the high resistance necessary to be given to the coils of the electro-magnets.

The arrangement of the brushes in the commutators of electro-magnets must also be considered; many forms have been employed, from the cylindrical or conic roller to the pencil or brush composed of a bundle of metal wires, of which we have already spoken. The last plan is nearly always reverted to, because among so many contacts there are always sure to be some good. Besides, they divide the spark, are less quickly worn away than simple divided plates, and they may easily be so arranged that they can be drawn out as required when worn away.

Methods for increasing the distance through which the attraction acts.—One of the greatest difficulties encountered in the application of electro-magnetism as a motive power, is the excessive shortness of the stroke made by the parts subjected to the effects of electro-magnetic attraction; and it has for a long time been a subject of consideration, how to increase the length of this stroke, whether by mechanical or by electrical means; this has been more or less accomplished in several ways, which we will rapidly review.

As the attractive force decreases with the distance nearly as the square of the distance or even more, the first consideration was how to profit by this rapid

decrease of force so as to increase the play of the movable parts. For this it was sufficient to make the armatures of the electro-magnets react upon the parts employed to transform the movement by means of long levers. As the weakening of force from the lengthening of these levers was much less than the weakening of the attraction by reason of the greater distance from the armature, the result was that this distance might be lessened, at the same time furnishing a fair length of mechanical stroke. Several disadvantages, however—among others the loss of stroke, in consequence of the play in the pivots of the levers, the bending of these levers, and the inequality of the attractive action, which reached its maximum just when it should cease—caused this plan for increasing the stroke of the armature in electromotors to be given up. An attempt was then made to cause the attraction to act directly on the driving shaft by providing it with soft-iron plates, and arranging round it a certain number of electro-magnets, so that the current circulating in them successively, and bringing them very close to the armatures, the attraction was exerted at a short distance. Further, a revolving wheel was made to move in a space surrounded by electro-magnets; and this wheel, in passing from one electro-magnet to another, acted on a crank fixed to the driving-shaft. But in these arrangements there were also many drawbacks, owing, first, to the too great rapidity of the commutation of the current, which prevented the electro-magnets

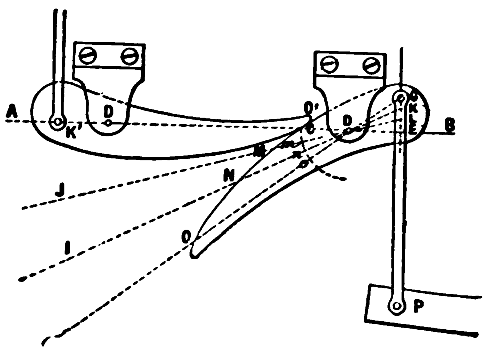
from attaining their maximum force; secondly, to the formation of strong induction currents, which acting in the contrary direction to the working current, weakened its action; and lastly, to the effects of residual magnetism, which was a considerable impediment to the working of the motor.

Following these different arrangements of electro-magnets, it was suggested to substitute for them the dynamic effects of currents, particularly the attraction of iron cylinders inside magnetising coils. In this way residual magnetism was avoided, and a better attractive stroke obtained; but the slight energy of this force was deceptive to those who first tried this arrangement. It was the same with the propelling force of electro-magnets, by which the armatures, moving at an angle to their poles, were attracted till their axis coincided with that of the electro-magnets. By this arrangement, as much as 14 centimetres of attractive stroke could be obtained; but the power was reduced, with respect to the normal attraction, in the proportion of 33 to 6. Then several natural philosophers tried to take advantage of the considerable increase of the attractive force in proportion as the armature approaches the electro-magnet: either to increase the initial attractive force by making it uniform, or, by means of mechanical appliances, to lengthen the stroke of the armature.

We shall not describe in detail these contrivances, the most important of which are those of Houdin and Froment, for they have scarcely been applied except in clockwork and in some electric instruments of

precision. A complete description of them is given in 'L'Exposé des Applications de l'Electricité'; we will only say that in Houdin's distributor, shown in Fig. 27, the armature acts on the parts to be moved by means of two bent levers resting one on the other,

FIG. 27.

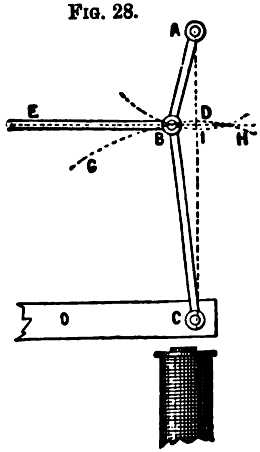


and arranged so that their point of contact is varied as the armature falls, and the power is exerted on one arm of a lever becoming shorter and shorter in the ratio of the squares of the distances through which the armature successively moves. Therefore, when the armature is at its furthest point from the magnet, the attractive force acting at the end of a long lever is considerably increased; whereas when the armature is close to the magnet this force is considerably diminished in consequence of the arm of the lever being very much shorter. As this distribution of the power takes place in inverse proportion

to the attractive power itself, a much greater and more uniform stroke is obtained than in the ordinary arrangements.

In Froment's distributor, shown in Fig. 28, the armature is suspended from a sort of crank working on a lever pivoted to a fixed centre, and the lever, acting on the parts to be moved, itself works on the pivot where the two rods join; it follows that if these rods are so adjusted that they form an angle when the armature is at its greatest distance from the magnet, the two pieces in straightening as the armature is attracted describe at their pivot, and consequently the motive lever also, a course which is equivalent to the sine of the arc, whilst the attractive distance is equal to the versed sine. There is thus a longer stroke obtained, as also distribution of the force, for as the lever straightens the force developed by the magnet must increase considerably in power, to produce an equivalent mechanical effect.

Fig. 28.

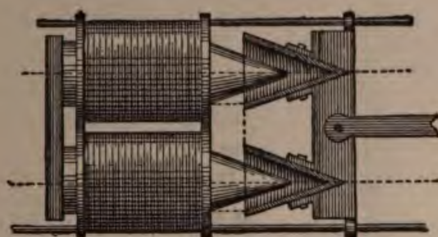


A small application of this arrangement was applied in Roux's motor, which we will shortly describe.

We must mention Pellis and Henry's arrange-

ment for lengthening the attractive stroke of the armature, which seems a modification of that of Hjorth, and consists of employing electro-magnets, as shown in Fig. 29, with conical poles acting on armatures in the form of funnels into which they are

Fig. 29.

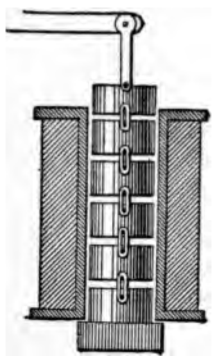


drawn. Thus the attractive distance is represented by the space separating the inside of the hollow armature from the conical pole, which distance decreases in proportion as the armature is drawn in, and the more pointed the pole, the longer is the stroke. A similar effect is obtained by making the armature in the form of a wedge, and arranging it between the poles of an electro-magnet bevelled to fit it. We shall speak later of Froment's motor founded on this principle.

In a motor contrived by Perrin, the iron core of the electro-magnets consisted of a sort of chain of iron cylinders (Fig. 30), joined by long links which held them together one above another. This chain, being placed inside a magnetising coil, contracted under the influence of the electric current in the coil

and the consequent individual magnetisation of the cylinders; and as the number of attractions equalled that of the cylinders, a contraction could thus be obtained corresponding to the sum of all the spaces between the cylinders. Of course this greater length of stroke could only be obtained at the cost of the electro-magnetic force developed, for these short cylinders could have no great magnetic force.

FIG. 30.



Methods employed to mitigate the effects of the extra current.—It being impossible to entirely avoid the extra currents created in electro-magnets at the moment of making and breaking contact, an attempt has been made to counteract their detrimental effects by secondary means. D'Arlincourt, Lenoir, and Billet proposed several ways of doing this, which, though solving the problem only very incompletely, especially for electromotors, are worthy of notice. In Lenoir's arrangement the electro-magnet is covered with a second coil of fine wire, furnishing induced currents, which, passing through the wire of the electro-magnet in the opposite direction to the exciting current, at the moment of breaking contact, causes the demagnetisation to take place more promptly and rapidly. D'Arlincourt's arrangement is similar to this, and seems even to have preceded

it. That of Billet is more complicated, but seems scarcely applicable to electromotors, for the coils of the electro-magnets are wound in opposite directions from the centre of the bobbins, and are joined one bobbin to the other where the change of winding takes place. One pole of the battery is connected by two wires to the two ends of the wire of one of the bobbins, and the other pole corresponds to the two ends of the wire of the other bobbin; the result of the circulation of the current through this system being that the magnetisation is produced as if the current came from two different batteries, each magnetising half the electro-magnet in the same direction. Thus the extra currents resulting from this arrangement mutually neutralise each other. However, an attentive study of this arrangement shows that the action is only complete for the extra-currents of demagnetisation. (See the description of these arrangements in 'L'Exposé des Applications de l'Electricité,' by Th. du Moncel, vol. ii. pp. 101 and 102, and vol. v. p. 359.)

Methods employed to diminish the effects of residual magnetism and magnetic inertia.—The means employed to weaken the effects of residual magnetism properly so-called, i. e. that due to the imperfection of the iron, consist in choosing the softest iron possible and remelting it several times, or rather employing certain kinds of grey cast iron, which, according to Deprez, are very perfect for this use; but the effects of residual magnetism caused by magnetic condensation can only be destroyed by a

contrary electrical action, and the best way is, immediately on the breaking of contact, to send a feeble current in the opposite direction. A Planté secondary cell, composed of two small lead plates introduced into the circuit of the electro-magnets on Jacobi's plan, solves the problem about as well as the contrary induced currents mentioned before. However, these methods till now have not been much employed in electromotors, and have only been applied to telegraphy. There should evidently be trials made in this direction. We have seen, besides, that in employing electro-magnets with the cross-piece divided by a piece of copper, according to Hequet's arrangement, the residual magnetism is greatly diminished.

As for the inherent disadvantages of magnetic inertia, the best plan is to diminish the magnetic mass of electro-magnets, to employ tubular electro-magnets and armatures composed of thin plates of iron placed side by side, and to make several slits in the magnetic cores and the surrounding metal surfaces; but the best solution of all is to employ continuous current electro-magnetic motors, as in the reversible machines of Gramme, Siemens, Meritens, and others.

PART I.

FIRST PHASE OF ELECTROMOTORS.

CHAPTER I.

HISTORICAL SUMMARY.

To whom belongs the honour of having first applied electricity to work a mechanical motor? This is a question which it is very difficult to answer correctly. From the electric whirligigs constructed to demonstrate the action of the electric fluid, either by its flow from points, like the whirligigs worked by static electricity, or by the effect of successive attractions, as in Zamboni's dry pile tourniquet, many scientists have endeavoured to utilise in some such way the dynamic actions of currents; especially when the powerful force of magnetisation developed by these currents was learnt. If we may believe the story given in the 'Electrician' of Sept. 9th, 1882, Dr. Schulthess promulgated the first idea in a lecture at the Society of Engineers of Zurich in 1832, in which he asked "if a force, such as we obtain by interrupting the current and establishing it again,

could not be advantageously applied to mechanics." This idea must have borne fruit, for in January of 1833 he brought before the notice of the same Zurich society a machine, in which the principle enunciated by him was successfully applied. In November, 1832, Salvator dal Negro, Professor of Natural Philosophy at the University of Padua, also published an account of means employed by him to apply electro-magnetism to the motion of machines. Also in 1834, Professor Jacobi, well-known to the scientific and industrial world by his discovery of electro-plating, published the arrangement of an electro-magnetic motor which, afterwards tried on a larger scale, enabled him to accomplish on the Neva those grand feats which created so much wonder in 1838. The following is what he said in the account he published of his experiments: "I had the honour, in 1834, to present to the Académie des Sciences of Paris, a paper on a new electro-magnetic apparatus. This paper was read at the meeting of December 1st, and an extract was printed in 'L'Institut' of December 3rd, 1834.* Since that time Botto and dal

* The following is the extract referred to:—"M. Jacobi, of Kœnigsberg, presented to the Académie a paper on a magnetic engine of his invention, in which magnetism is employed as a motive power. The following is the description he gives of it: The apparatus consists of two systems of eight bars of soft iron, 7 in. long and 1 in. in diameter. These two systems are placed at right angles, and so arranged on two discs that the ends or poles of the bars are opposite one another. One of these discs is fixed, while the other revolves on its axis, and the movable bars are thus made to pass as close as possible before the fixed ones. The sixteen bars are wound with 320 ft. of copper wire, 1¼ line in diameter, and the ends were in contact with a voltaic apparatus. The whole mass,

Negro * have claimed priority of invention, and my ideas coinciding with those of such distinguished men forms a further proof of the importance of this new motive power."

After his first experiments Jacobi continued his researches, and in 1838, with funds provided him by the Emperor of Russia, he constructed a large machine which we will describe further on, and under-

moving with a speed of 6 ft. per second, gives about 50 lbs., being a considerable *vis viva.* The work thus furnished, measured by an apparatus similar to the Prouy brake, is equal to a weight of 10 or 12 lbs. lifted 1 ft. per second. This success is principally due to a novel construction of the commutator, by which are worked the changes of polarity, which take place eight times in each complete revolution; that is to say, eight times in half or three quarters of a second, the ordinary speed of the machine, when the water in the cell is so little acidulated that the development of gas is hardly appreciable."

* The following is the description of Botto's motor, as published in the *Institut* of December 3, 1834, p. 400:—"The mechanism of which he makes use consists in the first place of a lever worked, like that of a metronome, by the alternate action of two fixed electro-magnetic cylinders acting on a third movable cylinder attached to the lower arm of the lever. The upper arm imparts a continuous circular movement to a metal fly-wheel in the ordinary manner. The apparatus is so arranged that, the axes of the three equal cylinders being in the same vertical plane perpendicular to the axis of movement, the oscillating cylinder places alternately each of its extremities in contact with one or other of the two cylinders placed on each side of it; and each time at that instant the direction of the magnetising current in the helix is changed, the rest of the circuit maintaining the same direction, so that poles of the same name are produced in the fixed magnets and the movable one. The change of direction is worked by means of a lever operated by the movement of the machine itself. In consequence of this arrangement the movable cylinder undergoes simultaneous alternate attraction and repulsion, whereby the apparatus sets itself in motion, which motion is maintained by the magnetic force of the electric current."

took his great experiment of electric navigation. The boat employed by him was a ten-oared rowing-boat, fitted with paddle-wheels rotated by his electro-magnetic machine, shown in Fig. 31. The boat generally carried ten or twelve people, and the runs sometimes lasted the whole day. However, the difficulties that he met with in the electric generator and the imperfections in the construction of the motor often caused break-downs which it was difficult to remedy on the spot. However, when they were overcome, Jacobi was able to estimate the work produced, and he showed that a battery of platinum plates of 20 square feet surface could, by this means, be made to develop one horse-power; but he always hoped to obtain the same result with half this battery surface. The boat, according to report, went about four miles an hour, being a better result than that obtained at the first trials of small steam-boats. According to Jacobi, the boat was 28 feet in length, 7 feet 6 inches in beam, with a draught of water of 2 feet 9 inches. At the experiments in 1859, the machine, which occupied a small space, was worked by a battery of 64 platinum cells, each having 36 square inches of surface, and charged on the Grove system with nitric acid and acidulated water. When the boat, with twelve or fourteen people on board, went against stream, she could make three miles an hour. If we compare these results with those obtained in 1838, it will be seen that already great progress had been accomplished, for in the first trials it was necessary to use a battery nearly

five times as large. These details were mentioned in a letter written by Professor Jacobi to Faraday on June 21st, 1839, which may be read in the 'London and Edinburgh Philosophical Journal' of September, 1839.

The publication of this letter brought out a letter from Professor Forbes, of King's College, Aberdeen, to Dr. Faraday, dated October 7th, 1839, in which, wishing to obtain the honour for his own country, he gave the detailed account of the experiments undertaken in the same direction by Mr. Robert Davidson, an inhabitant of Aberdeen.

According to this letter, it appeared that at the time of Jacobi's experiments, i. e. in 1839, this Robert Davidson had a lathe and a small locomotive capable of being worked by electricity. His carriage, when running on rough planks, was able to carry two people, and it was said that it could easily be proved that the work at these machines had been in hand two years before the date in question. However that may be, it appeared that Davidson had not confined himself to the invention of his motor; he had also brought out several improvements in Daniell batteries for their application to electromotors, and he had determined the best kind of iron for this sort of application. Although Forbes at this time was in communication with the authorities of the railway companies to obtain from them for Mr. Davidson, pecuniary assistance in his very important and costly experiments, it was he who in the first instance defrayed all the expenses, and he was able to show

in Edinburgh some mechanical saws and lathes, a printing-press, and a locomotive, worked by electro-magnetic power. It was only later, in 1843, that he was able to obtain any assistance.

At the same time that these results were obtained in Europe, the Americans on their side were not inactive. According to the English paper from which we have borrowed some of these particulars, a Mr. Davenport, a blacksmith of Philadelphia, constructed in 1836 an electro-magnetic motor which worked a lathe and a printing-press, and this press printed the paper started by the inventor under the title of 'The Electro-magnetic and Mechanical Intelligencer.' However, as will be found in the 'Comptes rendus de l'Académie des Sciences,' of June 8th, 1840, in a letter from Messrs. Patterson, of New York, on an electro-magnetic machine applied, according to them, to the printing of Mr. Davenport's weekly paper, it appears that to Messrs. Patterson, and not to Davenport, must be attributed the invention of the machine mentioned in the English paper. This invention is described in the following manner in the 'Comptes Rendus':—

"Pieces of soft iron are placed at equal distances round the circumference of a wheel, and pass during the rotation of the wheel one after the other in front of two electro-magnets. The wires bringing the current are fixed to a simple mechanism, which enables the current to pass at the moment when each piece of soft iron is on the point of coming opposite the magnet. When it is as close as it can

get, the current is broken, the wheel continues to move by its acquired velocity, and the current is re-established when more than half the space separating the pieces of soft iron has been traversed. The attraction beginning at will, either a little before or after this middle point, determines the direction in which the wheel will work. It is therefore only necessary to very slightly move the apparatus making and breaking the electric contact, to reverse the machine. The machine is stopped and fixed by allowing the current to act continuously; cutting off the current altogether leaves the wheel perfectly free.

"The electric power for this machine is obtained from a battery of amalgamated zinc and sheets of platinised silver. Pieces of sheet iron platinised may be used with advantage instead of the silver plates. These elements are plunged in water acidulated with sulphuric acid in the proportion of nine parts of water to one of acid."

In 1838, Captain Taylor, an American, took out a patent for an electro-magnetic motor, which was also protected in England on November 2nd, 1839. The description of this motor, accompanied by drawings, may be seen in the 'Mechanic's Magazine,' vol. xxii. p. 694. It was more simple than that of Davidson, constructed about the same time, if not even earlier. The arrangement employed for the making and breaking of electric contact was about the same in the two machines.

We shall presently describe Davidson's motor;

but, to complete our history of the invention of electric motors, we must record the fact that between the years 1841 and 1844, a certain number of electric motors, more or less ingenious in their construction, were brought out by Wheatstone, Elias, de Harlem, and Froment. One of the three motors patented in 1841 by Wheatstone altogether resembled that of Froment, represented further on (Fig. 37), which has long been looked upon as one of the most ingenious ever constructed; and what is the more curious is, that a Hungarian inventor called Jedlick claimed the same model as having been invented by him in 1829, which date, however, can be in no way guaranteed; and it is again this model which, being tried on a very much greater scale in 1856 by Marié Davy, was the object of especial commendation accorded by the Académie des Sciences.

CHAPTER II.

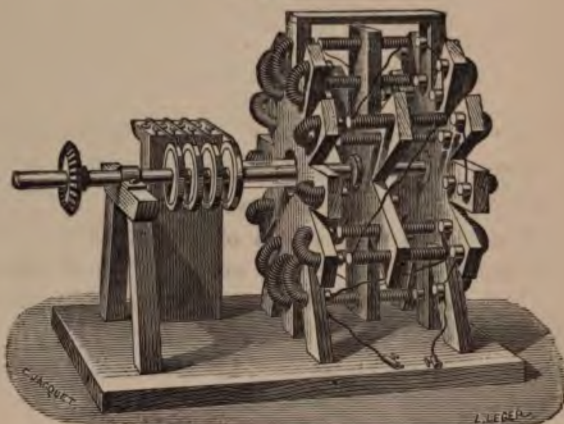
HISTORICAL MOTORS.

THE motors we are now about to describe are those which may be called historical, for, beyond having a celebrity at the time they were made, they have served as types to a crowd of others after them which are only more or less modifications of them. We shall then go through them in chronological order, beginning with Jacobi's motor, the first of all motors, and of which we have hitherto only given an outline.

Jacobi's Motor.—As has been seen, Jacobi, in 1838, perfected the first motor, of which he gave a description in 1834 before the Académie des Sciences in Paris, and it is this motor as applied to his boat that is shown in Fig. 31. It was composed of two circular rows of horse-shoe electro-magnets, carried by two vertical supports, and between these two rows revolved a sort of star fixed to a horizontal axis. This star had six points and carried six pairs of straight electro-magnets. The axis also carried a commutator formed of four wheels regulating the direction of the current, so that when the straight bars were between two consecutive poles of the horse-shoe electro-magnets, they were always attracted towards

one and repelled from the other, the change of direction in the current taking place directly the movable poles were opposite the fixed ones.

FIG. 31.

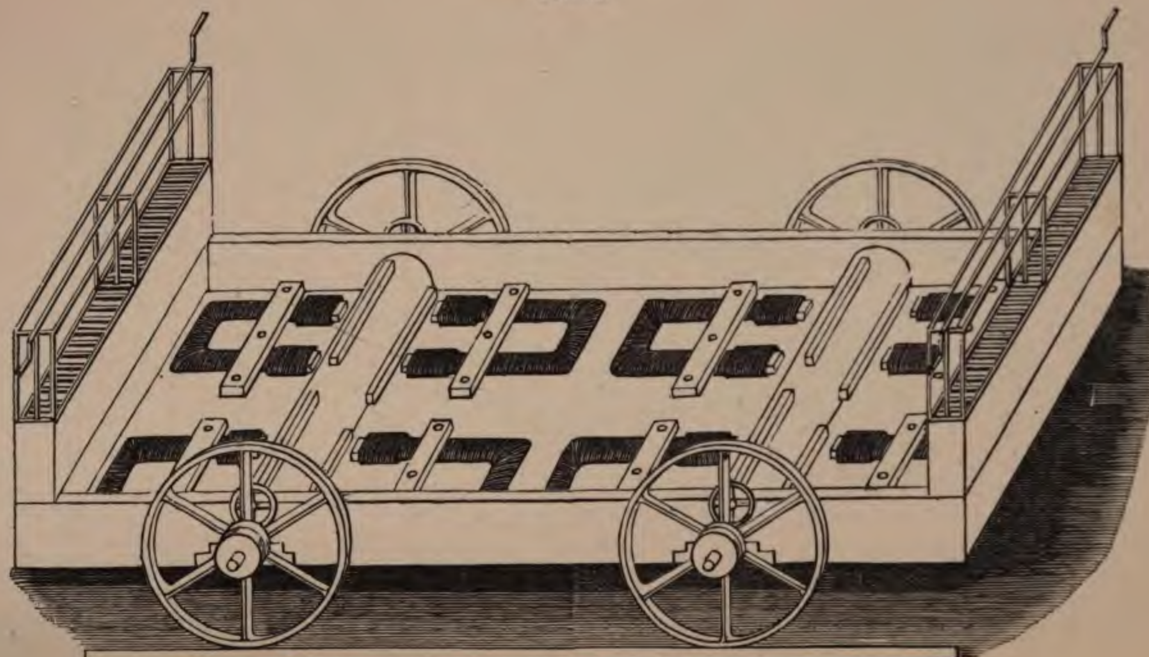


From the particulars published in several papers, the figures relating to the experiments made on the Neva were as follows:—In the first experiments a battery of 320 Daniell cells was employed (sulphuric acid and sulphate of copper), the plates of zinc and copper having each 225 square centimetres of surface, and the speed obtained being 2300 metres per hour. In the second experiments, made in 1839, the battery consisted of 128 Grove cells and similar surface, and the speed obtained was 4170 metres an hour with 12 passengers on board. The dimensions of the boat were 8·40 metres in length, 2·25 in beam, and a draft of water of ·90. These experi-

ments cost the Emperor Nicholas at least 60,000 francs.

Davidson's Motor.—The motor which Mr. Davidson applied to his locomotive is represented in Fig. 32, for which cut we are indebted to the 'Electrician'; and as will be seen, it consisted of two cylinders of wood fitted to the axles of four wheels and furnished with four sets of iron armatures arranged so as to turn between the poles of eight electro-magnets. These were fixed horizontally at the bottom of the carriage, and were arranged two and two by their opposite poles in two parallel rows, so that each cylinder carried two sets of iron bars parallel to the axles, and presented themselves successively during the rotation of the cylinders to the poles of the corresponding opposite electro-magnets; so that when one of the bars on one side was opposite its electro-magnet, one on the other side was just within range of the attraction of its electro-magnet, and *vice versâ.* In this arrangement, if the current was interrupted in the active electro-magnet and sent into the one on the other side, the movement once started continued, and produced a rotary movement in the axle. Each of the four sets of armatures produced the same effect, and added together, developed sufficient power to turn the wheels of the locomotive. The commutators for making and breaking the current were little different from those used at the present day, only Davidson employed two batteries in troughs placed one at each end of the carriage, one acting on the electro-magnets on the right, and one on

Fig. 32.



those on the left. For this the axles carried at each end two small metal cylinders, on which pressed the brushes in connection with one of the batteries and the electro-magnets belonging to the one set. These cylinders were composed of two parts—one plain, and one with a number of grooves corresponding in number with the armatures; and these grooves were filled with ivory. The current from the battery arrived at one of the cylinders by the rubber pressing on the plain part, then passed from there by the metallic parts of the cylinder to the electro-magnets of the right or the left as the case might be, and thence to the battery; but as, in consequence of the movement produced by this current, one of the ivory parts was brought under the brush, the current was broken in the electro-magnetic system which had produced the movement, and not being held back by the attraction of the armatures, the cylinder continued its movement by virtue of the acquired velocity, and the action going on at the other end of the axle. The position of this commutator was in fact such, that when one ivory part was under the brush of the first commutator a metal part was under the second, and caused the current to flow from the second battery through the second system of electro-magnets.

The batteries employed by Davidson were those of Sturgeon, composed of plates of iron and amalgamated zinc measuring 15 inches by 12; each was divided into two parts, so that each set of magnets had its own battery; there were 40 elements arranged in

the same way as Wollaston's trough battery. This battery could also be reinforced by a spare battery of 19 cells fitted on the platform of the carriage, which was 16 feet in length, 6 in breadth, and weighed 5 tons, including the batteries and the mechanism. The speed attained was said to be four miles an hour. Engineers estimated the power thus developed on a line of rails at less than a horse-power, but the author of the letter whence these particulars are obtained believes that the power developed was much greater.

The electro-magnets employed by Davidson were made of plates of iron bound together; each of the arms was 25 inches in length, and the rectangular poles were 8 inches by 5, and were only 4 inches apart. The magnetising coils were composed of bundles of cotton-covered wire. At first the magnetic poles were almost in contact with the armatures as they passed before them, but the enormous attraction in a straight line which was then developed and which bent the supports, necessitated the separation of the parts, which of course produced a diminution of the power developed; and this circumstance somewhat discouraged the inventor.

Wheatstone's Motors.—The conceptions of this inventor being always remarkable for their ingenuity, we must describe the different models mentioned in his patent of the 7th of July, 1841, and as we shall have occasion presently to describe that already referred to, which figured at the recent Electrical Exhibition in Paris, we shall only now

describe those shown in Figs. 7, 8, 9, and 10 of his patent.

In one of these motors the magnets consisted of teeth set widely apart on a large iron wheel round which were wound the magnetising coils, and the connections of these with the battery were so arranged that contrary poles were alternately presented. There were 24 of these coils, and each pair formed a two-armed electro-magnet, and the wheel was fixed in a vertical position. On the conical surface formed by the iron teeth acting as electro-magnets, was a circular crown of iron, belonging to a wheel whose axis was carried at one end by a vertical ball and socket movement, and at the other by a crank on a flywheel shaft, the latter carrying also a pulley and commutator with twelve insulated contact pieces. This commutator, by means of rubbing springs, sent the current from one electro-magnet into the following, as the iron wheel revolved round the circle of electro-magnets, and this rotation resulted from the movable wheel passing from one electro-magnet to another taking different positions on account of its axis being fixed at one end, thus imparting circular movement to the crank to which it was fixed at the other.

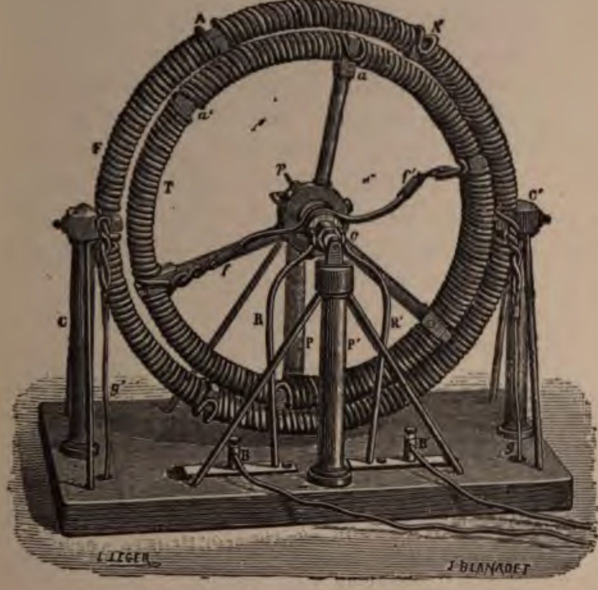
The second motor consisted of six straight electro-magnets so arranged as to form the sides of a hexagon, without, however, their poles being in contact. This hexagon was fixed in a vertical position, and parallel to it a movable plate fitted with three horse-shoe permanent magnets, so arranged

that the arms formed the spokes of a wheel. The electro-magnets were so wound that the adjacent poles were of the same name, so that when one of the spokes of the wheel was before one of these double poles so as to be attracted, the following spoke, which was of contrary name, was also attracted by the preceding double pole, the same being the case with the remainder of the spokes. It was only when the wheel had passed the spaces opposite the poles of the electro-magnets, that the current being interrupted allowed the wheel to continue its rotation by its acquired velocity, until being brought before a new pair of poles the same effect was repeated; but it was necessary that the current should be reversed, and for this purpose the commutator was composed of a double wheel and four brushes.

Elias's Motor.—This motor, constructed in 1842 by Elias of Haarlem, was of quite a different pattern, and with the transformation it underwent at the hands of Pacinotti and Gramme, furnished excellent results. In this motor the electro-magnets were circular, and their action entirely different from the effects till then utilised in the construction of such machines. Fig. 33 shows this motor as seen at the Paris Electrical Exhibition of 1881. It is composed of two concentric rings of soft iron, the one fixed, the other movable. The exterior ring, supported by the columns C C′, have six enlargements, as at A A′, dividing it into six equal parts. Between these enlargements is wound insulated copper wire, and

the winding is such that a current, entering by the wire *g* at one end of the horizontal diameter, is divided between the two halves of the ring, and leaves at the other extremity of the same diameter by the wire *g'*. Further, owing to the reversed windings, the poles A A', etc. are alternately north and south.

Fig. 33.



The interior movable ring is similarly constructed. Its six poles are always alternately north and south, and the current enters at one end of a diameter by the wires *ff'*, which are in connection with the commutator *c*. This latter is composed of six equidistant plates of copper, three in connection

with the wire f, and the three others with f'. To work the motor a special battery may be coupled to the exterior ring, and the principal battery to the terminals B B′, whence the current reaches the commutator by the springs R R′; or else one battery may be used, when B must be joined to g' and B′ to g. In either case the alternate north and south poles of the exterior ring remain the same. The poles of the movable ring, however, change their names at each sixth of a turn, and the commutator is so arranged that each pole of the movable ring is always repelled by one of the fixed poles and attracted by the other. In the figure, for example, if A′ is north a' is south, and is attracted by A while it is repelled by the south pole at the end of the column C. When a' arrives opposite A, the change of polarity takes place and a' becomes north and is then repelled by A and attracted by A′. The same actions are also going on at all the other poles, and all help to produce a continuous rotation. It must also be explained that the solenoids producing the magnetisation of the different poles in the two rings are very close together, so that there is also exercised between the movable pieces and fixed coils attraction and repulsion, due to parallel currents, and this assists in the rotation of the motor.

Froment's Motors.—His first motor, constructed in 1844, and shown in Fig. 34, has long been a sort of classical type, and has often been reproduced by a number of constructors as a specimen of an electromotor for practical demonstration at science classes. It was a crank motor, in which the attractive force

exercised on the armature, pivoted on the magnet itself, was transformed into a circular movement by means of a double lever working on a connecting-rod and crank shaft carrying a heavy fly-wheel. An eccentric on this same shaft making and breaking

Fig. 34.

the contact with the battery constituted the commutator, and this, closing the circuit when the armature was at its maximum distance from the magnet, set up an impulse which turned the fly-wheel till the armature was at its lowest point. At this moment the eccentric withdrew the contact and the electro-magnet lost its power, but by reason of the acquired

velocity of the fly-wheel the movement was continued until the armature was lifted up and had passed the dead point. A continuous circular movement was thus obtained, similar to that of a grindstone.

This apparatus, as also all the other motors of Froment, are in the collection of the Conservatoire des Arts et Métiers, thanks to the generosity of his talented successor and nephew, M. Dumoulin Froment.

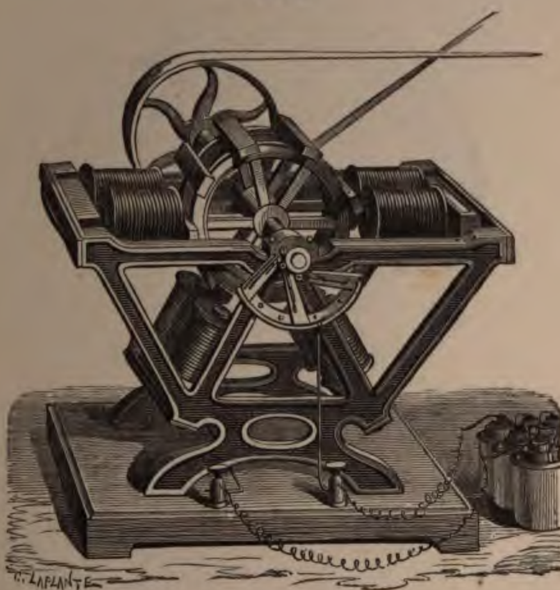
After the preceding motor, Froment constructed one in 1845, founded on the principle of a toothed wheel, in which the electro-magnetic force acts directly on the driving-shaft without transformation of the movement. It is the best-known model and the one most often found in a natural philosophy collection. It is shown in Fig. 35, and will be easily understood.

Four electro-magnets, fixed on an iron bed-plate, are arranged like spokes round a wheel on the shaft, provided with a number of soft-iron armatures. A commutator, composed of spring-rollers in contact with each of the electro-magnets and the battery, is worked by means of small cams on the driving shaft, and sends the current successively and alternately through the two pairs of electro-magnets, whose armatures are to be acted upon. These armatures, giving way to the attraction, revolve the wheel, and thus a continuous rotary motion is obtained. This motor has often been applied to work small model pumps, and other laboratory experiments.

The motors devised by Froment after those just

described, and which date from 1847, are represented in Figs. 36, 37, and 38. That shown in Fig. 36 was called by him an epicycloidal motor with movable magnets. It consisted of a large bronze vertical circumference, furnished inside with twelve iron

FIG. 35.



armatures, and inside which moved from one armature to the other a ring of electro-magnets with two arms, equal in number to that of the armatures, and supported by a sort of nave working in the driving-shaft. This latter worked in two strong pillars, and corresponded with a cogged wheel seen

in the drawing at the back of the machine. A commutator, fitted on the nave and against which pressed a spring rubber, successively sent the current through the different electro-magnets, rendering them alter-

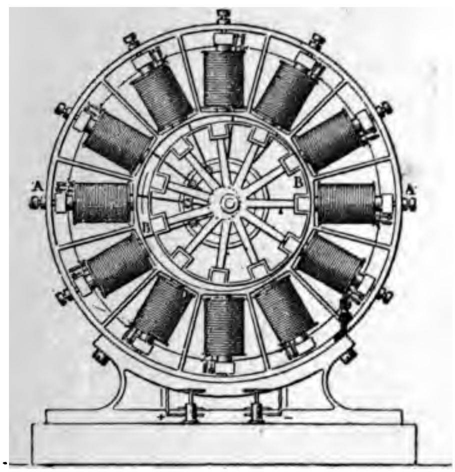
Fig. 36.

nately active and passive, producing between them and the armatures on the bronze ring successive attractions, which tended to revolve the whole system round the interior of this circumference. The axle thus received a circular movement, acting

on the end of a lever whose length corresponded with the difference between the diameters of the two circles.

Notwithstanding its ingenuity, this arrangement presented a grave difficulty which gave Froment the idea of reversing the arrangement and constructing the model shown in Fig. 37. The above-

FIG. 37.



mentioned difficulty was the continual bending in consequence of the normal attractive action of the bronze ring, which always ended by losing its round shape, and therefore hindered the interior ring from revolving regularly. Also the relatively great weight of the moving parts was another disadvantage, and by making this carry the armatures and the circum-

ference the electro-magnets, the same movement was obtained under much better conditions; for the electro-magnets could be strongly embedded in a double circular cage A B, solidly rivetted to them, and they could be arranged in a ring all round the

Fig. 38.

ring of armatures. This was the same plan adopted by Wheatstone in 1841, and made use of by Marié Davy in 1855.

Thinking that the effect produced between the fixed and movable systems in his direct-acting motor

might advantageously be shared by both, by putting both in movement and combining these two movements into one by means of cogged wheels, Froment constructed, in 1848, the motor shown in Fig. 38, which he called his triangular electromotor. This arrangement enabled him to act on three sets of drums carrying armatures with a single set of electro-magnets.

In this arrangement the electro-magnets, to the number of three or six, are rectangularly fixed round a movable vertical axis, turning on a point in the centre of the triangular stand, at the corners of which worked the three vertical drums, each furnished with three armatures. The axle of these wheels terminated below in cogged wheels, which worked on a central one on the axle of the electro-magnets, and a commutator, similar to those already described, was fitted on the upper part of the axis.

When the electro-magnets come within range of the armatures on the moving drums, they mutually attract one another, and thus give movement to the whole system; but since the result is that the electro-magnets also move and follow, the movement is continued, and the combined actions are accumulated by gearing; so that the commutator has only to establish the current through the electro-magnets when they

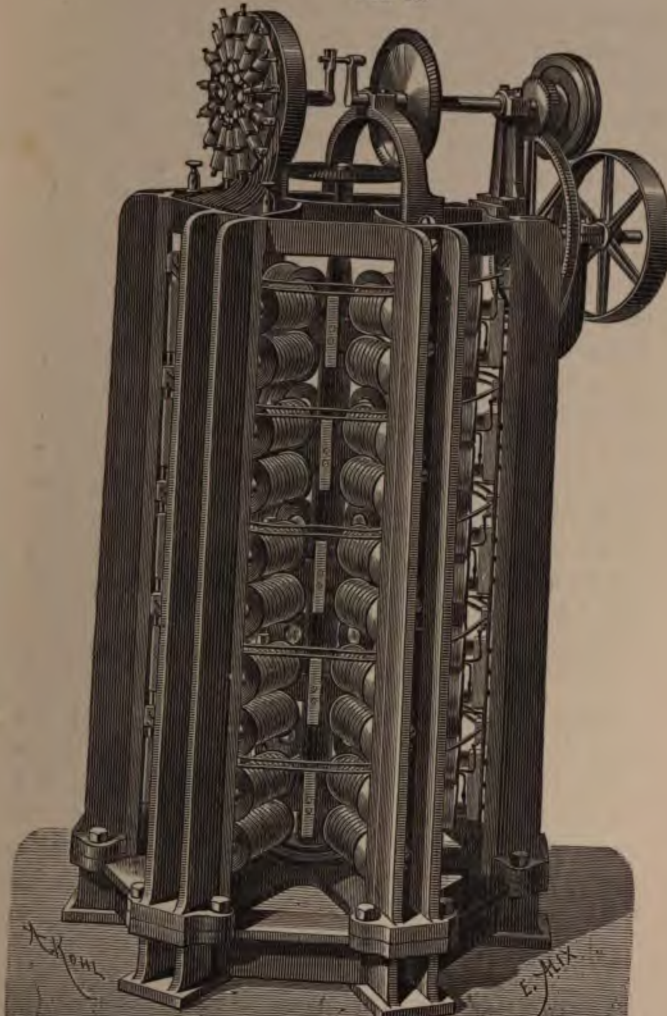
FIG. 39.

are near the corresponding armatures of the nearest drum, and to break it when the parts are in their nearest position to each other. Fig. 39, which is a plan of this machine, gives a very good idea of this arrangement, which, however, has not given results superior to other similar direct-acting motors.

Fig. 40.

The same year, 1848, Froment constructed several other motors, as shown in Figs. 40 and 41, of which one was named by its inventor a wedge electromotor. In this machine there are four electro-magnets, fixed opposite one another in pairs, and slightly inclined from the horizontal, and the armatures are in the shape of elongated wedges, which work vertically in

Fig. 41.



grooves, which guide them in their upward and downward motion. They are each fitted to a connecting-rod working on a crank shaft, on which is a fly-wheel and eccentrics acting as commutators. These two wedges are, of course, so arranged that when the attraction on one commences that on the other ceases, and *vice versâ.* When one of the wedges is at the top of its stroke, its two angular faces are at their maximum distance from the magnetic poles, and it is then that the current excites the electro-magnets; these then draw the wedges down till their thickest part is in the axial line, when the current is broken in these electro-magnets and sent by the commutator into the others, which are then in the position originally occupied by the first set, thus continuing the action. In this case the attractive effect is tangential, and is the result of both lateral and direct attraction; however, no special advantage has been derived from this arrangement.

We show, at Fig. 41, the large direct-acting rotary motor, which Froment constructed to work the dividing machines in his laboratory. All the electro-magnets were fixed vertically, one above another, on six iron uprights, forming the sides of a very solidly built hexagonal prism. In the centre of this cylindrical case, bristling with electro-magnets, was placed the rotating shaft, having throughout its length a series of vertical armatures placed end to end, and arranged to correspond with each of the pairs of bobbins. This shaft terminates above in a

wheel, which, acting on another of equal diameter, worked the commutator seen on the left of the figure, and also cogged wheels to reduce the speed of the pulley on the right, by which was worked the necessary machines.

The commutator was composed of a double set of wheels round the axis of the shaft, pressing on plates alternately insulating and conducting, joined to the different sets of electro-magnets.

It was said that this motor had a force of three-quarters of a *cheval vapeur*, but Froment often said that the power was much less than this, notwithstanding the alterations he made in this motor in 1862.

Such are the motors of M. Froment which for so long were regarded as perfect, and which cost their author much time and money. He, however, never had great expectations with regard to this application of electricity, and I have often heard him express his doubts as to the future thereof. Certainly, the most ingenious mechanical contrivances had been made use of in this type of machine, but the physical effects to be dealt with were not then so perfectly understood as at present, and it is only recently that any favourable results have been obtained, and that in quite a different direction.

Page's Machine.—This machine, brought out in 1850, was founded on a property then little known, namely, the attraction of solenoids, which has since furnished several important types of machines. We have mentioned on p. 14 this sort of

attraction and its advantages; unfortunately, the force developed is slight, and it is only with great reserve that we can accept the results announced by the newspapers of that time, results which were summed up as follows in the American paper, 'The National Intelligencer':—

"Professor Page, in the course of lectures delivered by him at the Smithson Institute, has shown that before long electro-magnetic action will have dethroned steam and will be the adopted motor. He has, to convince his audience, shown some most astonishing experiments. An immense iron bar weighing 160 lbs. was lifted by the electro-magnetic action, and was rapidly raised and lowered, dancing in the air like a feather, and without any apparent support. The force acting on the bar was estimated at about 300 lbs., although it was exercised through a distance of ten inches. One can hardly form any idea of the noise and brilliancy of the electric spark when it is drawn from a certain part of the great apparatus; it is a regular pistol shot. At a little distance from this point the spark makes no noise.

"The professor also showed his machine of four or five horse-power, worked by a battery contained in a space of about 3 cubic feet. It is a double-acting machine, with a two-feet stroke, and the whole thing, engine and battery, weighs about a ton. When the motive power is connected the engine works admirably, making 114 revolutions a minute. Applied to a circular saw of 16 inches in diameter, which cut into strips planks of 1½ inch in thickness, it made

80 revolutions. The force acting on the great piston throughout a stroke of 2 feet was estimated at 200 lbs. when the engine was going slowly. The Professor was not able to calculate accurately the force exerted when the engine was going at working speed, but it was much less."

If these results had been really obtained, it is clear that this machine must have been at once widely adopted, and it would never have been necessary to seek in other countries by numerous combinations to arrive at infinitely inferior results. There is evidently, therefore, in these accounts a great deal of exaggeration; nevertheless, these results produced at the time great excitement in scientific and commercial circles, which greatly contributed to the impulse then given to electric motors, and which caused, as we have said, much ruin. However, the following is the description of Page's machine as taken from the patent granted in France the 9th of September, 1850:—

"Page's machine was vertical, and was composed of two bobbins, each wound with a wire 1500 metres in length. If one coil had been made use of in each cylinder, the attraction of the iron bar would not have been made use of over a great length, as it would only have been powerful in the middle part of the bobbin; but Mr. Page has increased the attractive field by forming his bobbin of a series of small coils independent one of another, and put in action one after the other by means of a commutator. Thus the iron rod was drawn in from the top to the bottom

with a uniform movement. The two pistons were two cylindrical bars of soft iron, 3 feet long and 6 inches in diameter, and the stroke was 2 feet. By means of a lever and crank they acted on the axle of a wheel and imparted rotary motion to it. This fly-wheel was 600 lbs. in weight."

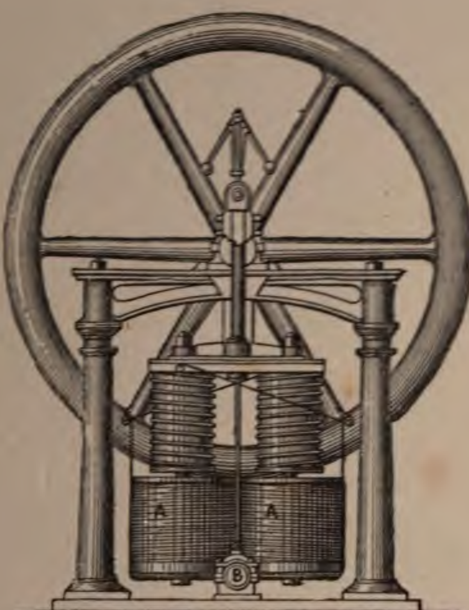
Notwithstanding the assertion of the American paper, Page's patent only claimed for this motor half a horse-power, and, if we believe Armengaud, the battery employed to work this machine consisted of forty Grove cells, of which the plates were 25 centimetres square. The trials, of which this machine was the result, cost, according to Figuier, 800,000 francs, which were given to Mr. Page by the United States Government.

Hjorth's Motor.—This motor, which was shown at the London Universal Exhibition of 1851 and received a grand medal at that Exhibition, was patented in 1849, and appears to have been an adaptation of Froment's angular motor already described. We shall see further on that Pellis and Henry also constructed a motor on this same principle. The apparatus was described in the above-mentioned patent as follows:—

"Fig. 42 represents an elevation, Fig. 43 a section of the machine. A A is a hollow horse-shoe magnet, cone-shaped inside, wound with copper wire, and so fixed that it oscillates about the centre B, supported by plummer blocks, as is shown. Inside this magnet are fixed a certain number of conical pieces of different lengths. The figure shows another horse-shoe electro-

magnet C C, conical outside, with openings corresponding with the cones placed inside the magnet A A. The magnet C C moves on the guides D D, fixed to the top of the support of C C and to the bottom of A A. A crank attached to C C works in

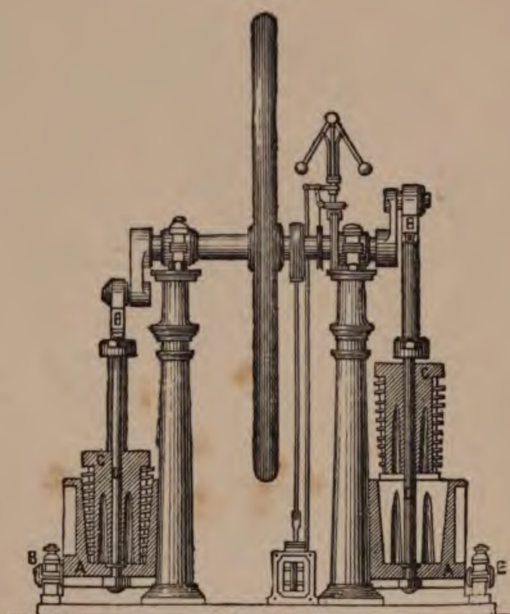
FIG. 42.



the ordinary way the shaft of a fly-wheel. A commutator O acts in the same way as the slide-valve of a steam-engine, and is worked by an eccentric rod. The machine may be reversed by an eccentric regulating the supply of current to the commutator; the

current from the commutator enters the wire of A A, and thence goes through the wire of C C, and then to the battery by the conducting wires. As soon as the current goes into the bobbins they exercise a mutual attraction, not only in the ordinary manner,

Fig. 43.



but because the magnets are so formed that the inside of the exterior magnet and the outside of the interior magnet form angles with the direction of movement, and at the same time the cones of different lengths are presented to the poles of the

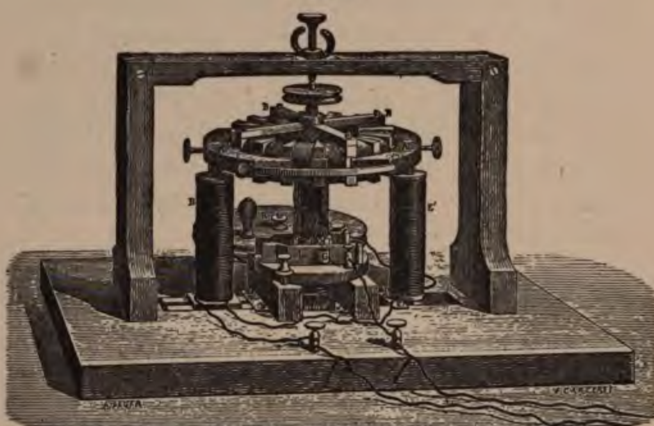
respective magnets, a constant force is maintained throughout the whole stroke by the successive portions of the surface which are brought to bear one after the other during the whole stroke. On arrival at the bottom of one set of magnets the direction of the current is changed, and the other set of magnets becomes active through the passage of the current in their coils, as has already been described. In order to prevent the circuit being broken and to maintain the action of the magnets, the sliding contact of the commutator is long enough for the collector in communication with one set of magnets to be in contact before the other is broken. By the preceding arrangement an alternate motion is obtained, similar to that of an oscillating steam-engine, and this motion may be applied as desired by means of cranks, shafts, &c."

The patent gives many further details as to the construction of the commutator, &c., but they are not of sufficient interest for us to give them here. All these details may be found, if desired, in 'La Lumière Electrique' for January, 1883, to which we are indebted for the accompanying cuts.

Pacinotti's Motor.—One of the most important motors brought out during the first period of the invention of electromotors, and at the same time that which presented the greatest originality and novelty in the physical effects introduced, is that which Pacinotti invented in 1861, and which was described in 'Il Nuovo Cimento' in 1864 in the following terms:—

"I took a turned iron ring furnished with sixteen equal teeth. This ring was suspended by four brass arms B B (Fig. 44), which fixed it to the axis of the machine. Between these teeth little triangular pieces of wood were let in, wound with silk-covered copper wire. This arrangement was to obtain perfect insulation of the coils or bobbins thus formed between the iron teeth. In all the bobbins the wire

FIG. 44.



was wound in the same direction, and each was formed of nine turns. Each is thus separated from the other by an iron tooth and the triangular piece of wood. On leaving one bobbin to commence the next, I end the wire by fixing it to the piece of wood which separates the two bobbins. On the axle carrying the wheel thus constructed I grouped all the wires, of which one end formed the end of one

bobbin and the other the commencement of the next, passing them through holes for this purpose in a wooden collar fixed on this same axle and thence attaching them to a commutator also on the axle.

"This commutator consisted of a ring or small cylinder of wood, having on the circumference two rows of grooves, in which are fitted sixteen pieces of brass (eight in each row); they are placed alternately, and concentric with the wooden cylinder on which they form a spindle. Each of these pieces of brass is soldered to the two ends of wire corresponding with two following bobbins; so that all the bobbins are connected, each being joined to the following by a conductor, of which one of the pieces of brass of the commutator forms a part. If we put two of these pieces of brass in communication with the poles of a battery by means of two metallic rollers G, the current, in dividing, will go through the coil at both points where the ends of the wire fastened to the pieces of brass communicate with the rollers; and magnetic poles will appear in the iron circle in the diameter perpendicular to A A′. On these poles acts a fixed electro-magnet, which determines the rotation of the circular electro-magnet; the poles of the circular electro-magnet when in movement always appearing in the fixed positions corresponding to the communication with the battery."

This machine is particularly worthy of notice, as it may be considered a veritable Gramme induction machine, and Pacinotti from the first so well understood its capabilities, that he described it in his

'Mémoire' as follows:—"It seems to me that what increases the value of this model is its faculty for being transformed from electro-magnetic into magneto-electric with continuous current. If, instead of the electro-magnet, there was a permanent magnet, and the circular magnet was made to turn, we should have, in fact, a magneto-electric machine which would give a continuous induced current always in the same direction. To develop an induced current by the machine thus constructed, I brought to the magnetic wheel the opposite poles of two permanent magnets, or I magnetised by means of a current the fixed electro-magnet, and I made the circular electro-magnet to turn on its axis. In both cases I obtained an induced current always in the same direction. It will easily be seen that the second method is not practicable, but that an electro-magnet is easily replaced by a permanent magnet; the electro-magnetic machine resulting from this will have the advantage of giving additional induced currents all in the same direction, without necessitating the use of mechanism to separate the opposite currents or make them converge."

Pacinotti closes his 'Mémoire' with this interesting remark, which seems to be the first indication of the reversibility of electric motors: "This model," he says, "further shows how the electro-magnetic machine is the complement of the magneto-electric machine, for, in the first, the current obtained from any source of electricity circulating in the bobbins produces movement of the wheel with its consequent

mechanical work; whilst in the second, mechanical work is employed to turn the wheel and obtain, by the action of the permanent magnet, a current which may be transmitted by conductors to any required point."

The Pacinotti machine remained for a long time forgotten in the Philosophical Museum of the University of Pisa, and it was only when the Gramme machine made its appearance, in 1871, that that of the learned Italian was recollected and brought before the public. It was sent to the Vienna Exhibition of 1875, and every one will have seen it at the Paris Electrical Exhibition of 1881, where it attracted great attention from those interested. We have dwelt much upon this machine, for it was with Gramme machines that the first experiments were made in 1873 with respect to the reversibility of dynamos, which have led to our knowledge of the transmission of power and all the attendant interesting results which have attracted the admiration of electricians of the present time: which results we will more fully consider in the second part of this work.

CHAPTER III.

EARLY ELECTROMOTORS.

In the preceding chapter we have described in the order of their date the arrangement of the primitive electromotors, and have specified their particular characteristics. But as, since the year 1844, inventions have succeeded each other with great rapidity and have become extremely numerous, we have thought it better for clearness of description to abandon the chronological order and consider the apparatus in different classes, grouping together those founded on the same principle. Looking at the question thus, we find that all the systems, until the time when it became really an industry, may be classed under four heads, viz.: 1. Electromotors founded on the dynamic properties of currents; 2. Electromotors founded on the attraction of iron to electro-magnets, and on the properties of electro-magnets; 3. Electromotors in which the attraction of gravity is introduced as a source of power: 4. Electro-chemical motors.

I.—ELECTROMOTORS FOUNDED ON THE DYNAMIC PROPERTIES OF CURRENTS.

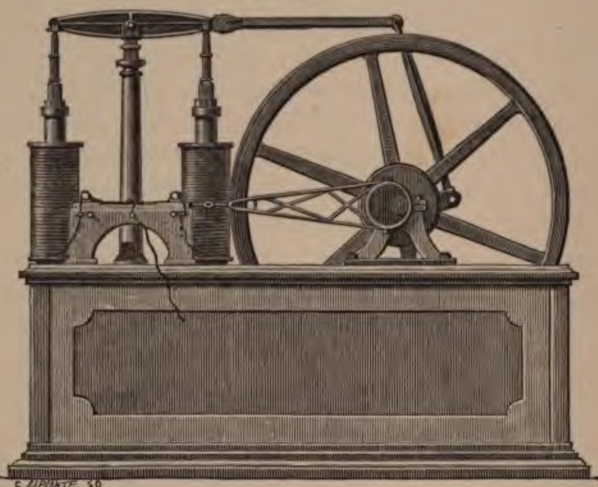
Barlow's wheel, Faraday's tourniquets, Zamboni's dry-pile application, and a number of other instru-

ments of this sort, are really so many electromotors founded on the dynamic properties of the current, as much magnetic as electric. However, as they are not capable of producing an appreciable force, and as mechanical combinations have no part in their construction, we will distinguish them essentially from the electromotors of which we are about to speak, and of which the most interesting are those founded on the attractions exercised on them by solenoids, through which a current circulates in the same direction.

Electromotors founded on the Attraction of Solenoids.—In these electromotors one of the solenoids consists of the coil of a magnetising bobbin, the other of the magnetic current produced, according to the theory of Ampère, in a cylinder of soft iron brought near to the tube of the bobbin. As soon as this receives a current, it develops an attractive action, which tends to draw the cylinder into the tube till its two extremities coincide with those of the bobbin. The laws of this sort of attraction were given in vol. ii. of 'L'Exposé des Applications de l'Electricité,' and the results have lately been applied by Marcel Deprez to a mechanical hammer, represented in Fig. 46, of which we will speak later. Doubtless the force developed under these conditions is not as considerable as that resulting from the attraction of magnets, but it has the advantage of continuing the magnetic attraction through a considerable length of stroke, and it is often applied at the present day, especially for arc lamps.

The first motor founded on this principle was, as we have seen, that constructed by Page in America; and it was said by some of the American papers, particularly the 'National Intelligencer,' that it developed five horse-power with a battery occupying the space of about one cubic metre, and that it gave the piston a two-feet stroke, throughout the whole

Fig. 45.



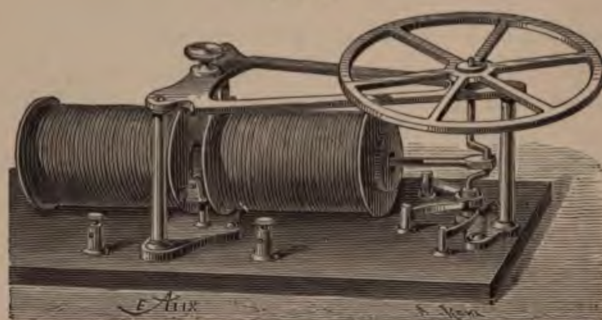
length of which a force of 600 lbs. was continually exerted. In other papers it was said that this machine was used to work a printing-press. We have already expressed our views as to these reports, and it is certain that if such a machine had existed, such fabulous sums would not have been expended Europe on further fruitless attempts. This motor

has been the model for several others, of which one of the best known is that of Bourbouze, which we give in Fig. 45, and which was constructed for the Natural Philosophy classes at the Sorbonne.

Bourbouze's Motor.—This motor, as we may see, was arranged like a fixed steam-engine with two pistons. At the two extremities of a horizontal beam were suspended two iron cylinders working in two long magnetising bobbins, the lower ends of which were filled by short iron cylinders joined together by a piece of iron between the bobbins, thus forming an electro-magnet. As soon as the current passed into one of the bobbins, the corresponding iron rod was attracted by the coils and also by the magnetic pole at its lower part, and it was drawn in until the current was cut off by the commutator; at this instant, the other bobbin being excited by the current, the beam, yielding to the new attraction, raised the first iron cylinder and placed it in a position to commence another stroke at the change of current. The transformation of the to-and-fro movement resulting from this double action was utilised, as in steam-engines, by means of a crank and fly-wheel; and as it was necessary to increase the length of the stroke, the connecting-rod was attached to the end of a long lever working on the end of the beam. The commutator consisted of a plate rubbing alternately on two contacts fixed horizontally on a table, and set in motion by an eccentric rod worked in a similar manner to the slide-valve of a steam-engine.

Du Moncel's Motor.—In 1851 we ourselves constructed the little motor represented in Fig. 46, the arrangement of which reminds one of an oscillating steam engine. Originally the working of this apparatus was not easily understood by the public, because the effects of the attraction of solenoids were not then well known; but a consideration of Fig. 46 will suffice to explain at once

Fig. 46.



the different movements which come into play. We see that the iron cylinder, which, in the position of the crank in the figure, passes right through the right-hand bobbin and penetrates to the depth of a few millimetres into that on the left, is on the point of being attracted by this latter bobbin; and when it arrives at the end of its stroke, it is within reach of an iron ring terminating the left-hand bobbin, which gives it an extra impetus capable of carrying the fly-wheel over the dead point corresponding to the movement of the shaft in the opposite direction;

the commutator, placed on the axle of the fly-wheel, has then cut off the current from the left-hand bobbin and connected it to that on the right, by which the piston is made to accomplish the retrograde movement preparatory to making another forward stroke, and so on.

To prevent friction, it was found necessary to arrange, between the two bobbins, a roller on which the iron piston moves; and as the piece which supports this roller and the piece connecting the two bobbins are suspended on pointed pivots, the driving crank of the fly-wheel, joined direct to a shaft fixed to the extremity of the piston, can follow this in its movement to and fro, causing the oscillation of the whole system at every half-turn accomplished by it.

In this apparatus the commutator is composed of two eccentrics fixed to the axis of the fly-wheel, and insulated one from the other; a fixed silver spring, in connection with one of the bobbins, encounters at each half revolution of the fly-wheel one of the eccentrics, and a third spring, large enough to bear on both the eccentrics, brings the current successively to the two latter, and works the changes in them.

In another double-acting motor with four pistons these magnetic properties have been turned to better account, by cutting the pistons in two and joining the ends two and two by a thick copper ring; then each bobbin has two rings of soft iron instead of only one. The result is that the pistons not only are no longer hindered in their movement by their

magnetic action, when passing from one bobbin to another, but they are still acted upon at both poles at once by the coils of the bobbins towards which they are moving.

Marcel Deprez's Hammer with Subdivided Coils.—In order to further increase the length of stroke of the iron piston of the motors already described, Deprez had recourse to the method employed by Page, i.e. a solenoid composed of a series of bobbins placed one after the other, and through which the current is distributed successively by means of a commutator. To these bobbins he has given the name of subdivided coils, and in this case the iron cylinder is attracted first by the first coil, then by the second and third, and so on until its whole course is accomplished. We have seen how Page built a motor on this principle, but Deprez has applied it to another end, and has turned it to good account as a hammer, which is shown in Fig. 47, and which he describes in the following manner:—

"In the apparatus tried at the Conservatoire des Arts et Métiers, the 15th of June, 1882, the sections constituting the electric cylinder A B of the hammer are eighty in number, forming a total length of one metre, both ends of each wire abutting on a collector of a circular form, seen at F G. The brushes of this commutator consist of two plates C E, C D, fixed to the double handle H C I, moving round the fixed centre C. These plates can be put at any angle to each other, so as to ascertain by trial the most suitable length to give the acting solenoïd. When this

FIG. 47.

angle has been determined, the angle E C D is made invariable by means of a clamp, and the apparatus is worked by giving the double handle H C I a circular movement backwards or forwards.

"The iron cylinder of the apparatus weighs 23 kilogrammes, but when the current has an intensity of 43 ampères and goes through 15 sections, the effort developed may be as much as 70 kilogrammes, that is to say, three times the weight of the hammer. And the latter will promptly obey the movements of the operator's hand."

Already, in 1851, we had ourselves contrived a combination of this sort, by which were made to work on an iron rod composed of alternate magnetic and non-magnetic parts, three bobbins, arranged in such a manner as to be successively attracted by the magnetic parts of the rod. We will give details of this system later, in considering electromotive apparatus, as well as the description of another of the same sort constructed a long time after by Bonelli. We only mention these arrangements at present to show to what use this sort of electro-magnetic properties may be put in electric applications.

Siemens's Single-bobbin Electromotor.—This motor, besides being of a very feeble power, is founded on the attraction of two electric currents going in the same direction, and on their repulsion when going in contrary directions. Supposing the two bobbins in Fig. 46 to be united into one, and the cylinder of soft iron to be replaced by a copper tube with an internal, well-insulated coil of wire, an idea of this

motor will be obtained, always supposing the commutator to be so arranged as to reverse the current.

Quite lately an attempt has been made to utilise the dynamic properties of currents, and among the best-designed motors we would mention those of Deprez, Bürgin, and Jablochkoff, which we shall describe more fully in the second part of this book; but their return is generally indifferent, so that it is not in these properties that the solution of the problem of electric motors must be sought.

II.—ELECTROMOTORS FOUNDED ON THE ATTRACTION OF IRON TO ELECTRO-MAGNETS.

1st. *Oscillating Motors.*

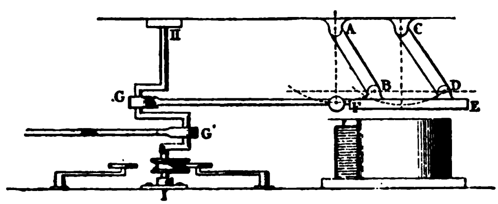
In these motors the electro-magnetic force results from the simple attraction of armatures working above the poles of one or more electro-magnets, which armatures, after having been acted upon by these magnets, rise in consequence of an interruption of the current under the action of an opposite force or that of the acquired velocity, to be attracted on the circuit being again closed. The result of this double action is a to-and-fro movement, which is then easily transformed into circular action by divers means more or less appropriate, in which lies the difference between the systems.

These motors, of which that of Froment, shown in Fig. 34, is one of the most simple types, are rather numerous; but as we cannot describe all, we will

only speak of the most interesting, and at the head of these machines we will place that of Roux, which, when tested with many others in 1855 at the Conservatoire des Arts et Métiers, showed the best results.

Roux's Motor.—The peculiarity of this motor was the means employed by its inventor to enlarge, in a simple way, the effective stroke of the pieces attracted, and the use of oblong tubular electro-magnets, which were new at this period. This motor

Fig. 48.



had only two electro-magnets, but they were very large and strong in proportion. Within reach of these, which were arranged horizontally one on each side of the motive shaft, were suspended by two jointed rods A B, C D (Fig. 48), two large plates of soft iron E F, E′ F′,* to which were fixed two long levers F G, F′ G′,* connected to a double crank G G′ on the driving shaft H I. On this shaft, as in all other electromotors, the commutator and the fly-wheel were to be found. When the motor was not in action, one of the plates was raised about two centimetres above the corresponding electro-magnet,

* The electro-magnet and shaft on the left hand of the machine are omitted in the sketch.

while the other one dropped. As soon as a current was sent into the apparatus the first-mentioned plate was attracted, but the rods supporting it describing an arc at the same time, the plate, while moving downwards, was drawn to one side. Now, the force utilised to act on the crank of the driving-shaft represents the sine of the arc, while the attractive force is only the versine, and the effective course of the connecting-rod was increased by this single fact, in the proportion of the sine of the arc to its versine. Doubtless the magnetic induction, in changing place, lessened the attractive force a little, but the gain in the greater play of the connecting-rod was considerably more than the loss.

When the mechanical action of the one iron plate was finished, the current was directed to the other electro-magnet, which, acting in the same way, continued the movement.

As may be seen from this simple description, this motor is only a double system of electro-magnets, whose armatures are separately worked, and this combination was the happier, as the enlargement of the stroke of the connecting-rods F G, F′ G′ * tended to increase the regularity of the electric action.

The following are Becquerel's remarks in his report concerning this machine, after the experiments at the Conservatoire in 1855:—

"M. Roux's oscillating machine, which, with the same surface of plates in the battery as that of Larmenjeat, consuming 6·6 kilogrammes of zinc per horse-power per hour, reduced the expenditure of

zinc to one-third, or 2·2 kilogrammes, with large battery surface; the cost in zinc alone per horse-power would be, according to these figures, 1 franc 50 centimes per hour. It is true that M. Roux employed very thick wire for his electro-magnets. However, the minimum expenditure of zinc per horse-power per hour, 2·2 kilogrammes, costing 1 franc 50 centimes for a machine not giving more than half a kilogrammetre, is still too high for electromotors to be at present successfully applied."

Fabre and Kunemann's Motor.—Fabre and Kunemann also exhibited, in 1855, a motor of large dimensions, in which they made use of their tubular electro-magnets.

These electro-magnets, two in number, were connected to the end of vertical shafts, which were joined by two rods to the cranks of the driving-shaft; they had their poles below, and were joined by two pivots to two large plates of soft iron, which served as armatures. These plates were fixed to the lower part of the machine, so that the electro-magnets themselves constituted the movable pieces. When at rest, one of the tubular electro-magnets was in a vertical position, while the other was inclined, hingeing on its two pivots. But when the current entered this last electro-magnet, the fixed piece of iron tended to bring it into the vertical position, and from this movement resulted an impulse which acted on the driving-shaft. At the same time the second electro-magnet was inclined, and the commutator, changing the current to this, caused a fresh impulse,

which continued the movement of the machine. This arrangement is not very favourable to the development of the force produced.

Dubos's Motor.—This motor, tried at the Conservatoire des Arts et Métiers in 1857, produced a power of 11·5 kilogrammetres under the influence of a battery of 70 Bunsen cells in tension, with a consumption of zinc estimated at 1·4 kilogrammes per hour, and the motor made 73·35 revolutions a minute. This was the most important result which had been obtained in France at that period.

The machine consisted of a sort of oscillating pendulum, on the two sides of which were fastened two sets of cylindrical electro-magnets, six on each side. Opposite to these movable electro-magnets were arranged six similar ones, fixed to a vertical framework, which could be brought closer to the magnets of the pendulum by means of a screw. The poles of all the movable electro-magnets on each side were in the same plane; this plane was not vertical, and only came into that position when the pendulum was swung sufficiently to one side for its electro-magnets to be almost in contact with the poles of the fixed electro-magnets. Now, the result of this arrangement was that, in the attraction produced by the reciprocal action of the electro-magnets on the same side, the upper electro-magnet of the pendulum, being the nearest to the corresponding fixed electro-magnet, was the most strongly attracted, and the whole movable arrangement was in consequence drawn nearer to the fixed electro-magnets; this increased

the attraction between the second magnets, then between the third, and so on to the sixth. When the lowest electro-magnet on the pendulum came in contact with its corresponding fixed electro-magnet, the current was cut off by the commutator from the first two series, and sent into those on the opposite side, and these then attracted the pendulum in the contrary direction, thus causing it to make a retrograde oscillation. An oscillating motion was thus obtained, which could be turned into rotary movement by connecting-rods, cranks, or any other known means.

M. Dubos's machine could be worked in three ways: 1st, by the attraction of the fixed electro-magnets only, the others then, acting only as armatures, not being excited by any current; 2ndly, by the reciprocal attractions of the electro-magnets of both systems, the poles being so arranged as to work with a current in the same direction; in this case the current was divided between the two series of electro-magnets on the same side, the poles being so arranged that each came opposite one of contrary sign; 3rdly, by combined attraction and repulsion, when a permanent current was sent through the movable electro-magnets, and a second current through the fixed magnets transferred alternately from one side to the other. The second of these methods produced the best results. There was nothing peculiar in the arrangement of the commutator in the different cases, and it may easily be imagined.

Gaiffe's Motor.—We have in Fig. 49 a representation of a little motor with alternate movement, which was used to work a small pump. It is a small experimental apparatus, very simple and interesting to show at lectures. Its electro-magnet is

FIG. 49.

straight, and both poles are utilised by means of a bent armature, like some motors exhibited in 1855 by Dezelu.

Gérard de Liège's Motor.—This is nothing but the application to motors of the electro-magnetic arrangement which the same inventor had applied to clocks. The arrangement consisted of a bar electro-magnet, whose polar extremities are prolonged and bent round till they face one another, and thus form a sort of elongated O with a break of

H

about 1 or 2 millimetres. In its mode of action this arrangement is similar to that of an electro-magnet whose poles are provided with iron rings, bringing the edges close together and acting on the armature by their adjoining extremities. The motor consisted of two such electro-magnets, fixed on a metal bed-plate, but not in the same plane, and forming an angle of 30°. An armature of soft iron, consisting of an elongated ring of the same size as the magnets, was placed between their polar extremities, and arranged so as to oscillate round its lesser diameter. This armature worked a connecting-rod on the crank shaft, so that the oscillating movement was turned into a circular one. A commutator, fitted on this crank shaft on the opposite side to the fly-wheel, sent the current into the two electro-magnets alternately. Owing to the angle formed by the latter, there was no dead point, and the impulse produced resulted from the attraction of both poles of the electro-magnet, which attraction was exhibited when the plane of the armature formed an angle with one or other of the electro-magnets, and continued till the two planes coincided. As this could happen only with one of the electro-magnets at a time, and its effect was to place the armature at an angle with the other, the change in the current which then took place caused an attraction in the opposite direction, thus continuing the movement.

Gautier's Motor.—This apparatus was designed to enable a long stroke to be obtained, thereby increasing the power of the connecting-rod, although

the attraction necessarily only took place through a very short distance. For this purpose a series of double electro-magnets were arranged side by side in pairs, each pair acting on ratchet wheels fixed to the rotating shaft. The electro-magnets of each set were placed one before the other with respect to the ratchet wheel, and the armature was carried by a jointed frame whose extremity acted on the ratchet wheel by means of a catch. These armatures worked freely in two notches in the sides of the frame, and could consequently be lifted up if, the frame continuing its downward movement, a rigid obstacle were encountered. This arrangement solved the problem M. Gautier set himself. From this position of the electro-magnets one before the other, and the working of the frame carrying the armatures, it resulted that, supposing one to be at a distance of 2 millimetres from the corresponding electro-magnet, the other might be at double that distance; the commutator being properly arranged with respect to the teeth of the ratchet, the current would excite the first electro-magnet, and would not arrive at the second till its armature was sufficiently lowered, in consequence of the inclination of the frame produced by the first armature, to act effectively and double the angle of fall of this frame, thereby letting one tooth of the wheel escape. This action being accomplished, the next set of magnets comes into play in the same way, and it will be understood how the movement is continued. As will be easily seen, these sets of electro-magnets may be of any

number, but M. Gautier considered that three were sufficient to obtain good results. To obviate the effects of remaining magnetism, he arranged a second battery and suitable commutators, so that a weak current in the opposite direction was sent through the coils of the electro-magnets which had accompanied their attractive action.

Roussilhe's Motor.—To overcome the great difficulty of the very short stroke given to the movable parts subjected to the electro-magnetic action, Roussilhe fitted to one of these, say a horizontal transverse piece, a series of bars each shorter than the previous one, and movable in the interior of the holes in which they were fitted. These bars carried at one end a soft iron armature, and at the other a head which kept them up when the horizontal piece was lifted, so that all the armatures formed a sort of steps. Under this series of armatures was a set of electro-magnets, each on a shunt from the main circuit, so that the battery might give to each the same force that it would have exerted alone. With this arrangement, the lowest armature, being within attractive distance of its corresponding magnet, produces a lowering of the transverse piece equal to the distance separating the armature from the electro-magnet (say 3 millimetres); but this lowering entails the approach of the second armature to its magnet, which, acting in the same way as the first, lowers the bar still further, doubles up the rod of the first armature into its case, and brings the third armature within the attraction of the third electro-

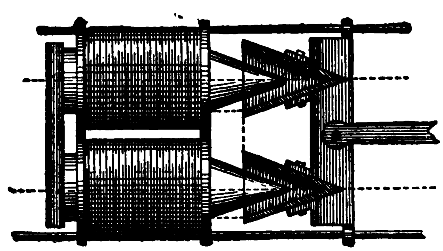
magnet. This continues through the whole series of electro-magnets, and the result is that the movement of the bar, which in the first instance was 3 millimetres, is now raised with 100 magnets to 30 centimetres, which distance is about equal to that of the to and fro movement of the piston in an ordinary small steam-engine.

To obtain a greater force with less intensity, Roussilhe arranged the aforesaid electro-magnets on several concentric circular lines, which required, for each series of electro-magnets in each circumference, a cross-bar provided with its rods and armatures. But as the attraction, which should be equally distributed round the central axis working the machine, would require the armature rods to be the same length for each circular bar, and could only be decreased in the common radius of these bars, the inventor preferred to make them annular armatures, supported by four small bars, which might then be fixed to a rigid cross-piece supported by the connecting-rod of the motor. These bars decreasing towards the centre of this assemblage of concentric rings, it happens that when the arrangement is raised these rings form in connection with each other a sort of conical figure above the group of electro-magnets, which may be coiled up spirally like a snail. At the first attraction the first ring is attracted, then the second, third, and so on till they are all brought close to the electro-magnets in the same plane. Now, the result of these successive attractions is that the crossbar to which the connecting-rod is fixed acquires a

considerable length of stroke, and in consequence, a movement is communicated to the beam which supports this rod. This movement being produced in the same way on the other side of the beam, by means of a similar electro-magnetic application working alternately with the first, a to-and-fro movement is obtained, which can be transformed into rotary motion in the same way as that of steam-engines made on the same plan.

Pellis and Henry's Motor.—At one time there was much talk about this motor, in which the increased play of the parts set in motion under the electro-magnetic influence was obtained by means of soft-iron funnels fixed to the armatures and of conical poles for the electro-magnets. This arrangement, already mentioned on page 39, is shown in Fig. 50;

Fig. 50.



but this plan, besides not being new, having been first demonstrated in 1849 by Hjorth, offered no special advantages, owing to the decomposition of the attractive force taking place in this case, and the continued displacement of the polarities excited.

The question of electro-motors was not solved by this apparatus any more than by others.

De Sars' Motor.—This is a modification of that of Roux, with an electro-magnetic arrangement which, according to the inventor, avoids the disadvantages of residual magnetism. It consists of a large electro-magnet with two arms, of which the bobbins act separately under the influence of a commutator, so that the electro-magnet always acts as a one-legged electro-magnet. Between the arms of this electro-magnet is pivoted on the cross-bar a piece of iron, which acts as a third magnetic core, and which carries at its other extremity two soft-iron armatures also pivoted, suspended above the two magnetic poles, on the side opposite to the pivots, by two connecting-rods; these rods keep the movement of the armatures nearly parallel, when the magnetic attraction tends to displace them laterally. The bobbins of the electro-magnets are wound so as to furnish two poles of the same sign, and the piece of iron supporting the armatures is terminated by a lever, which acts upon the crank of the motor and the commutator. This is of mercury, and arranged so that the current passes through the bobbins alternately after each movement to right or left of the intermediate arm. The result of this arrangement is that, though the electro-magnet acts under the influence of one bobbin only at a time, the attractive force developed on the armature is the result of a reaction produced by two contrary magnetic polarities; for the oscillating arm and the two armatures fixed to it are polarised, as

well as the cross-bar itself, in the opposite sense to the acting pole of the bobbin. As in Roux's plan, a normal attraction is therefore produced, which forces the armature to one side, thus inclining the oscillating piece to which it is fixed in the opposite direction to its original position; which results in an action on the crank of the motor and on the commutator, which sends the current into the other bobbin. But as the pole developed on this bobbin is of the same sign as the other, the cross-bar and the magnetic core of the first bobbin are polarised in the contrary direction to this pole, as well as the oscillating arm, which does not vary its polarity, and the contrary polarity which the magnetic core of the first bobbin possessed has its residual magnetism completely destroyed by this means, just when it might exert a detrimental effect on the raising of the armature first attracted.

2nd. *Motors with Direct Rotary Motion.*

In this sort of motor, some idéa of which may be obtained from Froment's model, represented in Fig. 35, the armatures are generally arranged round the circumference of a wheel or a cylinder, and successively receive the action of electro-magnets arranged in a circle outside this wheel, consequently exercising the same effect as water falling into the buckets of a water-wheel. Among the early models, we shall notice particularly those of Larmenjeat, Camacho, Cance, Trouvé, Cazal, &c. That of Larmenjeat has, however, a peculiarity of arrangement

which distinguishes it in a measure from ordinary direct rotary-movement electromotors: we shall consequently describe this very fully. Besides, it was this motor which, with that of Roux, attracted the greatest attention at the Exhibition of 1855; and the experiments made at the Conservatoire led Becquerel and Tresca to the following conclusions:

"Of the four machines submitted to experiment, only two, those of Larmenjeat and Roux, have shown results capable of furnishing useful deductions.

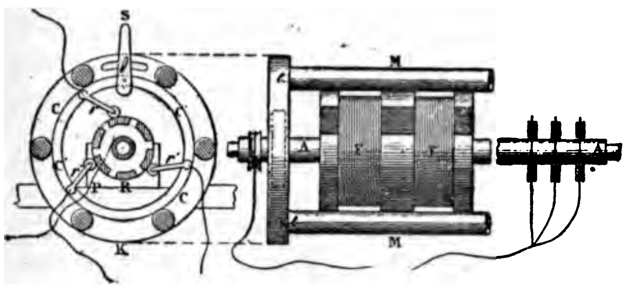
"Larmenjeat's rotary machine gave for minimum expenditure 4·5 kilogrammes of zinc consumed per horse-power per hour. Taking into account only the net price of zinc, say 70 centimes a kilogramme, and leaving out that of the acids employed, that of the waste in the cells, etc., we find that this consumption will cost about 3 francs 25 centimes per horse-power per hour."

It will be seen by this what small results had been attained in 1855.

Larmenjeat's Electro-Motor.—Larmenjeat very cleverly applied to his electro-motor the plan of circular three-pole electro-magnets, which we have represented in Fig. 12. In this machine, shown in Fig. 51, the armatures of the electro-magnets are movable. The armatures M M M are formed of six cylinders of soft iron, which turn on their axis by means of pivots *t t*. These cylinders are placed symmetrically round circular electro-magnets, which are three in number, and fixed together on the same axis of rotation, A. Only one of these electro-

magnets is shown in the figure. They are each, as may be seen, composed of three discs of iron cut on their circumference, so as to give six iron contact points and six copper parts, filling the intervals to a

FIG. 51.



depth of about a centimetre. These copper pieces are double the width of the iron ones, and the ring in the middle, according to the researches of Nicklès, is double the thickness of the outer rings.

The three electro-magnets, making together a length of about a metre, are so arranged with respect to the divisions of their discs, that the iron contact surfaces of each should not be in a straight line, so that the magnetic action, exerted on the soft-iron cylinders by the iron pieces representing the poles of these circular electro-magnets, takes place in the different points of the circumference corresponding to the copper pieces.

The commutator, represented at K to the left of the figure, is composed of a part moving with the axis, the wheel R, and a fixed 'part represented by

circles, C C and C′ C′. The wheel R is formed of six metal pieces. To the circle C′ C′, concentric to C C which holds the armatures, are fastened the rollers $r\ r'\ r''$, which press on the wheel during its rotation. Each of the rollers $r\ r'\ r''$ is in connection with one of the circular electro-magnets, and the current is brought to the conducting plates of the wheel R by a brush P.

To regulate the position of the rollers $r\ r'\ r''$ with respect to the conducting portions of the wheel R, a small lever S was fitted to the circle C′ C′, and this lever, by working an adjusting screw in a groove made in the circle C C, can adjust it so as to alter the degree of pressure of the three rollers, and even move it sufficiently to completely change the direction of the movement of the machine. It is easy, with this arrangement of commutator, to regulate the passage of the current into the three electro-magnets, and to make them act successively.

It will now be easy to understand the working of the apparatus. When the armatures M M are at a suitable distance to be attracted by the iron pieces of the electro-magnet F, the current will circulate through this electro-magnet, and the effect of the attractions exercised by these six iron pieces on the six armatures will be, to turn the electro-magnet, and consequently the shaft A, one-third of the arc corresponding to the space between the pieces of iron. By this movement, the iron pieces of the second electro-magnet are brought under the attraction of the armatures M M, from which arises a

further movement, producing a third attraction on the part of the last electro-magnet. It then becomes the turn of the first electro-magnet F again, and the preceding actions are repeated indefinitely as long as the current is supplied by the commutator K. Larmenjeat might have fixed the armatures M M, but by making them revolve there was no fear of their bending, and it was possible to bring the discs of the electro-magnets nearer in consequence. This arrangement is, as may be seen, extremely simple, and has given relatively good results.

Cazal's Motor.—This motor, exhibited in 1867, and designed to work sewing-machines, consists of an electro-magnetic bobbin or multipolar electro-magnet of great surface, formed of rough cast-iron, in order that its cost of production might be as low as possible. The motor, which may be fixed or movable, includes a bobbin and armature mutually attracting one another, and revolving when excited by the current. Sometimes the bobbin turns in the interior of the armature, which is then ring-shaped, and sometimes the armature has a cylindrical form, which then turns round the fixed bobbin. Both of them, armature and bobbin, have in their circumference hollows which are filled with magnetically insulating composition; so that when the current passes, only half the surface is magnetised, the other half remaining inert. A commutator, having on its surface as many conducting bars as there are divisions of the bobbin and armature, distributes the current; the motor may be revolved

from left to right, or right to left, according to the position in which the commutator is placed, or the direction in which it is worked; but once started, the rotation continues in the same direction, which is indispensable for sewing-machines. The sewing-machine to which it was fitted at the Exhibition of 1867, worked with the current from a battery of four Bunsen cells.

Camacho's Motor.—The style which Camacho seems to have preferred, is that shown in Fig. 50, only the electro-magnets which he adopted, and which were four in number, were multitubular magnets which he made square, that they might act more regularly; the armatures were composed of a large number of iron plates magnetically insulated one from the other by means of cardboard. These armatures, of which we have shown the advantages on p. 16, were of considerable breadth, and were in consequence somewhat bent; their employment in this kind of electro-motor is the more advantageous, since the electro-magnet, by reason of the multiplication of its tubular cores, can act longer upon them by its lateral attraction, as each core may exert its individual attractive effect on the armature, and also that, by reason of the square form of these cores, the sides which face the armatures exert their power parallel with the plates of the latter. The commutator of this apparatus is itself an excellent arrangement, as it allows of modifying at will the duration of the make and break of the current. For this purpose

it is fitted with contact plates cut sloping. With two rubbers arranged on adjusting screws, the contacts may be made to take place near the narrow or broad end of these plates; and consequently produce short or long contacts. With electromotors of the class of which we are now treating, it is difficult at any time to know when the closing of the circuit should begin and when it should finish, and this arrangement allows of easy regulation after one or two preliminary experiments. These machines, as we have already said, have furnished fairly good results; they worked sewing-machines and mechanical pianos very satisfactorily at the Exhibition of 1875. In order to avoid the employment of Bunsen batteries, which are very wasteful and disagreeable on account of the fumes given off by them, Camacho employed double liquid bichromate of potash cells.

Chutaux's Motor.—This machine, with the exception of the electro-magnets which are ordinary ones, very much resembles that of Camacho; like him, Chutaux employed multiple armatures, only the iron sheets which composed them, instead of being magnetically insulated by means of cardboard, were insulated by being galvanised, and the tin deposit was thick enough to obtain sufficient insulation. By reason of the similarity of these two motors, a lawsuit took place between the two inventors, which showed that, if Camacho first thought of using multiple armatures in motors, Chutaux had first patented the idea; besides it appeared that Froment

himself had constructed armatures of this kind, which were found amongst a quantity of electric odds and ends of all sorts, which he disposed of before his death. The commutator of Chutaux's motor has nothing to distinguish it from others, beyond two adjusting screws on the brushes which enable them to be regulated as they are worn away by the sparking. This arrangement had, however, already been employed in other machines. The trials made of this motor, at the Exhibition of 1875, were also tolerably satisfactory, and it appears from several letters from M. Debain that it also worked mechanical pianos.

Cance's Motor.—Cance uses in his motor the multiple-cored electro-magnets described on page 16. There are only two of these magnets horizontally arranged one before the other; the armatures, five in number, are arranged on the radii of a sort of star, of which the centre is the driving-shaft, which is therefore of course vertical. This shaft goes through the bed of the apparatus between the two electro-magnets and the centre, into which are fitted the spokes of the wheel which should be of wood or bronze, is so arranged that when the armatures arrive in the neighbourhood of the axial line of the electro-magnets, their lateral faces coincide with this line. From this arrangement it results that, when one armature is before one of the electro-magnets, it is first attracted by the arm of this magnet nearest to it, and as this attraction is successively exerted by the different magnetic cores

of this arm, it is soon brought within reach of the other arm, which then acts on it with its different cores as in the first case, until its lateral face has attained the axial line of the electro-magnet. The current is then broken, and as, with this kind of

FIG. 52.

electro-magnet, the remaining magnetism is very much diminished, the motor continues its course, until the second electro-magnet placed at the opposite side has commenced in the same manner its attractive action, which, however, takes place almost

instantly, by reason of the number of the armatures. By this arrangement each electro-magnet acts as if it represented two electro-magnets placed side by side, and, as with multiple-cored electro-magnets, the magnetic field is very much extended, since it is in proportion to the number of cores, and by this means may be obtained with a single electro-magnet a considerable attractive course, which reached nearly 10 centimetres in the model constructed by Cance. This, with ten medium-sized Bunsen cells, gave sufficient power to work a lathe, and turn a piece of wood 10 centimetres in diameter. M. Cance has recently perfected this motor, and made it into an induction machine, which was exhibited at Paris in 1881, and is shown in Fig. 52. This machine is of course then reversible.

De Sars' Motor.—This is founded on the same principle, as regards the arrangement of the electro-magnets, as that of the same inventor already described. As in that, the residual magnetism of the magnets not in action is almost destroyed at the moment when it might be disadvantageous.

The motor consists of a crown of tubular electro-magnets, slightly oval, on which roll, carried by an iron cross-bar, cylindro-conical iron wheels, of which the number is less than the electro-magnets, so that they may be at any moment in different relative positions to the electro-magnets. By this means these wheels, which act as armatures, are never out of action; there are always at least two which are under attraction. Further, as these wheels run on the

iron coverings of the electro-magnets which are always polarised in the same direction, the whole system of armatures, including the cross-bar carrying them, partakes of the polarity of these coverings, and communicates to the cores, when the current is not exciting them, an inverse polarity to that which the current gave them, which destroys, as we have said, the remaining magnetism. The driving pulley and also the commutator are placed on the axis of the cross-bar which carries the rollers; this commutator is nothing very remarkable, and consists of a wooden cylinder fitted with a brush of metal wires, which turns round a series of contacts in connection with the different electro-magnets.

It will be easily understood that, by putting another set of magnets base to base with those in the first-mentioned circuit of electro-magnets, and arranging another corresponding cross-bar with iron rollers, a double effect will be obtained.

We may add that these cylindro-conical rollers are hollow, in order to present less magnetic and mechanical inertia.

Trouvé's Motor.—M. Trouvé has at various times constructed a number of different motors, some of which are everywhere known under one form or another, to turn small instruments, more especially Geissler tubes.

The most simple form of these motors consists of a hoop of iron, provided inside with two enlargements shaped like ratchet teeth, inside which work two straight electro-magnets placed end to end. On a

current being sent through these when near the teeth of the hoop and interrupted as they pass them, the apparatus is set in motion, precisely as if the two enlargements were two separate armatures.

By making the iron hoop also movable, two opposite movements are obtained, the one from the action and the other from the reaction, thus demonstrating the law of mechanics that the two are equal. By fixing the electro-magnets, the hoop turns with a speed which may be calculated by the number of revolutions it makes a minute, and by stopping the hoop and leaving the electro-magnets free, these latter turn with a speed which may be shown to equal that of the hoop, if the two masses are equal in inertia.

The other motors of M. Trouvé resemble those described on page 65. One consists of a great number of electro-magnets forming a sort of magnetic wheel, which, as in Wheatstone's and Froment's motors, is fixed by its centre to the driving-shaft, and revolves inside a ring of soft iron by means of properly adjusted make and break of current. This is worked by a very ingenious commutator, as to which we must say a few words on account of its extreme simplicity. It consists of an insulating disc, through which pass all the ends of the magnet coils arranged in a circle; these ends being mechanically attached to a point in the driving-shaft, the disc describes a gyratory conical movement. Below this insulating disc is another disc of platinum, held by a spiral spring, which is always in contact with one or

other of the wires of the first disc, in whatever position it may be. Whence it follows that if the platinum disc and the electro-magnets are in connection with the battery, the ivory disc, by the movement of the magnets, will put the different ends of the coils in contact with the platinum successively, and the electro-magnets will consequently be excited one after the other.

In another pattern the magnetic action takes place in a normal direction, and by means of a long connecting-rod acting on a crank the machine is set in motion. The electro-magnetic action is, however, not exerted on the armatures in the ordinary way; these are in fact not pivoted close to the poles, but are held by a gudgeon working freely in a rigid piece placed between the two poles, and each electro-magnet has only one bobbin. By the action of the connecting-rod these armatures then are raised, now above the north pole of the electro-magnet, and now above the south pole, and work as if they were acted upon by two distinct electro-magnets. Generally, M. Trouvé fits these motors with only two sets of magnets, but he arranges the motive parts and the connecting-rod so that they may be removed at will, the electro-magnets being fixed, so that in this manner may be found the best length to give the connecting-rod to obtain the maximum effect. We shall see further on that he has also devised another arrangement, capable of application to the gyroscope.

Allan's Motor.—Twenty years ago this motor made

much talk, but it has, however, fared no better than others. Although the effects produced by it in the experiments made in 1857 at the Conservatoire were not very satisfactory (26 kilogrammes of zinc consumed per horse-power per hour!), we must, as a faithful historian, say a few words about it. The following is a description of it given at the time in the 'Cosmos':—

"Mr. Allan's machine is constructed on an entirely new principle. A sort of endless chain is provided throughout its length with soft-iron armatures; the electro-magnets are arranged round a cylinder. They attract the armatures of the chain and make it advance by successive steps in the same direction. This chain communicates the movement to whatever mechanism is required to be worked. One set of the armatures is first brought near to the corresponding electro-magnets, so that the attraction may take effect when the current is sent into the coils; the electro-magnets are excited, the chain advances, and brings a fresh set of armatures before a fresh set of electro-magnets, which become active at the moment when the first set is rendered passive by the stoppage of the current, and the movement continues in the same direction as long as the battery is in action. Instead of an endless chain, Mr. Allan sometimes employed a simple bar to which the electro-magnets impart a to-and-fro movement, which is transformed by well-known means into a continuous direct movement."

Is this the same Mr. Allan who about the same

time constructed an electromotor in which a long armature of the Siemens type was revolved between the poles of a powerful fixed magnet? In the American patents such an apparatus under this name will be found.

Pulvermacher's Electromotor.—This inventor constructed a direct rotary motor in which he employed sheet electro-magnets, similar to that shown in Fig. 15, and to avoid the production of induced currents and sparking at the commutator, he employed a carbon arrangement as commutator in which the current was gradually broken, thus constituting a sort of undulatory current. It was said that this motor worked well, but we cannot ascertain what force it developed.

Marié Davy's Motor.—"This motor," said Becquerel in a report made to the Académie in 1858, "is composed of sixty-three electro-magnets, arranged at equal distances round a wooden circle, inside which is a copper circle; all the electro-magnets have their axes pointing to the centre of the wheel, and their surface coincides with the concave surface of the copper circle. Inside this large wheel there are two others whose radius is one-third of that of the first, and both are provided with copper circles inside. These wheels have each twenty-one electro-magnets at equal distances, pointing towards their common centre, whose polar surfaces coincide with the concave surfaces of the copper circles. The small wheels can thus turn without friction inside the large wheel, and work by their movement the shaft of the

machine which coincides with the axis of the large wheel. The movable electro-magnets thus come successively in contact with the fixed electro-magnets. Both large and small wheels are provided with gearing, which maintains the coincidence when once established.

"The machine is so arranged that the electro-magnets are successively put in communication with the battery, and receive opposite polarity to each opposite pair of electro-magnets as they come into action.

"M. Marié also replaced the inner wheels provided with electro-magnets, by others having only armatures of soft iron; the movable part is thus lighter and the gearing becomes unnecessary. The soft-iron wheels then turn like rollers on the interior surface of the outer wheel, so as to come in contact successively with the electro-magnets at the moment of their magnetisation."

Although Marié Davy's machine was only copied from that of Froment, a sum of 2000 francs was granted to the inventor to make experiments on a large scale. We have not heard if these trials ever came to anything, and it may be doubted whether they have produced any more advantageous results than those already mentioned. Nevertheless, if Marié Davy's motor has nothing new in its electro-magnetic arrangement, the paper presented by him on this subject contains some interesting reflections on electromotors, and it is doubtless on account of this paper that he was rewarded. Among the

conclusions therein arrived at, there is one which it may be interesting to mention here, and we give the following extract from the said paper:—

"He thought" and rightly too, "that to obtain the maximum effect in these machines, the electro-magnets and armatures should be allowed to act till actual contact was produced, since the electromotive force, as he proved by calculation and experiment, decreases so rapidly with the distance, that when two electro-magnets are brought from a distance to contact they develop a quantity of work of which $\frac{5}{8}$ are in the last millimetre, and half the remainder in the last but one. Now, in most rotary electro-magnetic machines constructed up to the present time, the movable armatures pass rapidly before fixed electro-magnets, following a line perpendicular to the axis without actual contact. Thus all the work that might be obtained is not utilised."

De Molin's Motor.—Count de Molin is among those who persisted in the belief of the success of electromotors, and in fact he kept it to the end; for he was surprised by death in the midst of his researches, and when he had just succeeded in working with his own machine a small boat carrying fourteen persons on one of the lakes in the Bois de Boulogne. It is true that the trials made, at the Conservatoire des Arts et Métiers, of the power of this machine showed that it only developed a force not more than a seventh part of a man-power; but being assured that two strong men would be required to row his boat containing fourteen persons, he

believed the problem partly solved, and died in this persuasion. In 'Les Mondes' (vol. viii. p. 161, &c.) may be found reports of the trials undertaken by him in the years 1865 and 1866, which trials attracted a good deal of attention at the time. The following is the description given by De Molin, of his apparatus in a memoir sent to the Académie des Sciences in October 1866:—

"The force of electro-magnetic attractions is well known, and I have often asked myself why the motors based on this principle produce so little effect, the eighth part of a man-power from 30 large Bunsen cells; and I have always attributed it to residual magnetism.

"I then thought that this kind of motor should act slowly, to give the fluid time to accumulate and disappear, and that the moving parts should be made to continue their action till contact, but avoiding a shock, and producing direct rotary motion.

"The arrangements I have adopted are these: on two parallel planes, I arrange in a circle concentrically to the same axis two rows of electro-magnets, say sixteen in each plane. On the same axis, between the two planes, I place a bronze wheel with a shaft which does not revolve fixed in its centre, which can oscillate in any direction round its other end. To obtain this movement, two concentric revolving rings are used, the two axes of oscillation being perpendicular to each other. When the current is sent into the electro-magnets the wheel will be attracted by two diametrically opposite poles, the two magnets

coming into contact; and if we neutralise successively on each side the electro-magnet placed behind, the wheel will be carried without a shock on to the following bar, and this throughout the whole circumference, and the shaft will then have described a cone in space.

"The greatest distance between the zone and the armature is 34 millimetres, and the least half a millimetre, except, of course, actual contact; the wheel is 95 centimetres in diameter. There are always sixteen electro-magnets in action, eight of each sign. I was able, by gradually tightening the brake, to vary the velocity from 20 to 3 revolutions per minute without diminishing the available work, which appeared to me a valuable quality in a motor; and I concluded from this that the work, within the limits of a certain speed, is proportional to the quantity of electricity produced. I have applied this apparatus with 20 Bunsen cells to propel, by means of a paddle-wheel, a ferry-boat on the lake in the Bois de Boulogne, carrying fourteen persons against a head wind; the work developed was estimated about equal to that of two rowers."

This description not being very lucid, we think it advisable also to give that of the Abbé Moigns in vol. xi. of 'Les Mondes,' p. 417, as follows:—

"This simple and massive motor is a vertical bronze wheel provided on each flank with sixteen armatures, which in turn yield to the attraction of sixteen electro-magnets fixed on two circles parallel

to the wheel, and placed vertically, one to the right, the other to the left. The metal wheel does not revolve; it only oscillates round its centre so that each of the armatures successively comes in contact with an electro-magnet, drawn along by the magnetic attraction which is the motive force of the system. Let us suppose a group of these successive armatures, the first and most distant will be at a distance of 1½ millimetre from its corresponding electro-magnet, the second 1 millimetre, the third ½ a millimetre, and the fourth in contact. As soon as the contact is made, the current exciting the electro-magnet is broken, the armature, soon getting rid of the remaining magnetism, detaches itself, and withdraws, again to come in contact when its turn is come.

"The efficient working of the apparatus depends on the regularity of the commutator, the contacts of which, being protected from the destructive effects of sparking, should remain perfectly clean. To fulfil this last condition, the most difficult of all, the commutator works inside a trough filled with water in which a little potash is dissolved; this is renewed by letting it off by a cock when it is dirty. The current exciting the motor is furnished by a battery of 20 Bunsen cells.

"The motion produced in the wheel by the attraction is communicated to a shaft which, by means of two endless chains, works the two paddle-wheels of the boat."

According to this description, we may believe that this motor may be classed with those of Wheat-

stone, Froment, and Marié Davy, which we have previously described (page 60).

The experiments made in 1865 at the Conservatoire des Arts et Métiers with this machine, led to the following conclusions:—

"1. The greatest work developed by the machine per second may be estimated at 3·112 kilogrammetres; that is to say, taking 8 kilogrammetres as one man-power, it can furnish one-seventh part of a man-power.

"2. Its least consumption amounts to 17 kilogrammes of zinc per horse-power per hour."

These results, as may be seen, are but indifferent. However, there was a great deal of notice taken of this machine at one time.

Becquerel's Motor.—This arrangement, which preceded that of Larmenjeat, described page 105, is founded on the same principle; only, not being intended to produce great force, it is only provided with one circular magnet instead of three, and this electro-magnet has besides only two poles or rings. Here the soft-iron cylinders serving as armatures are replaced by fixed electro-magnets in the interior of an iron circumference, like those in Froment's motor, represented in Fig. 36. The electric action is exactly the same as in Larmenjeat's motor, only the commutator has to be more complicated, in consequence of the double action required of it.

Becquerel was enabled to demonstrate, by means of this apparatus, the truth of the reasoning we have given concerning the contrary effects of induced cur-

rents. Thus he found that the maximum velocity of the motor was obtained when the circular electro-magnet was in its natural state, and when the ends of the wire wound on it were not joined, which, as will easily be understood, would prevent the development of this induction current.

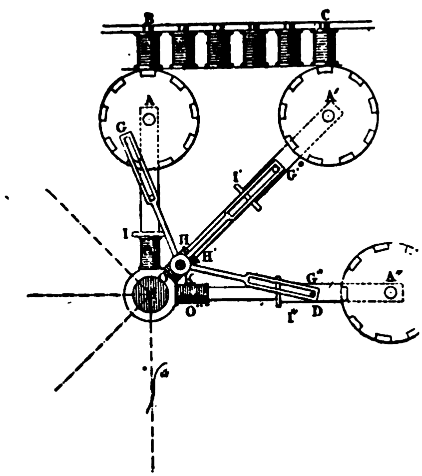
III. ELECTROMOTORS INTO WHICH GRAVITY IS INTRODUCED AS A SOURCE OF POWER.

Many, seeking perpetual motion, have racked their brains to destroy, by the lengthening or shortening of the lever, the equilibrium of a wheel provided with counter-weights. In spite of all their attempts, they were always obliged to come back to act in some manner, either on these weights, or on the levers supporting them. This problem, so dear to certain mechanicians, has lately been taken up by several persons introducing electricity as an auxiliary agent. Some wished to employ electricity to raise the weights whose fall had promoted the rotation of the motor; others, perhaps with more reason, tried simply to use electricity to modify the length of the levers supporting these weights. Among motors of this kind we will describe one constructed about twenty years ago.

Let us imagine, fixed on a movable horizontal axis, M (Fig. 53), some strong equidistant spokes, rectangular in shape, and constructed of a non-magnetic substance; we will imagine that these spokes have strong sheaths or cases, which can slide freely length-

wise, made of copper, terminated at their free end by a strong pivot, on which revolves a very heavy iron wheel, A, A′, A″, &c.; now let us suppose that from the point B to C are arranged in a straight line B C

FIG. 53.



a series of electro-magnets, one beside another. It will easily be understood that, if the wheels A, A′, A″ have their circumference cut and shaped like the iron discs of the circular electro-magnets of Larmenjeat's motor, i. e. composed of alternate copper and iron pieces, they will, by means of a commutator sending the current successively from one electro-magnet to another, be attracted from point B to point C, moving their support forming the cases of the spokes of the shaft M, and be left to themselves when leaving point C. The weight of these wheels

then being unequally distributed on the two sides of the motive-shaft, in consequence of the inequality of the length of the levers to which those weights are attached, this shaft is set in motion; but to make this motion continuous, these arms of the lever, on which the wheels A, A′, A″, &c., act by their weight, must be shortened immediately on falling from C to D.

To accomplish this the copper sheaths or cases supporting the wheels A, A′, A″ are provided with strong pegs, on which are pivoted rods G H, G′ H′, &c., turning on a common axis placed laterally and eccentrically at K on the side of the wheel. These rods had at G a small slit, of which we shall soon see the use. These same copper sheaths are also provided with strong pieces of iron I, I′, &c., at their lower end serving as armatures to the electro-magnets O, O′, O″, &c., fixed on the spokes of the motive shaft.

With this arrangement it will easily be understood that the rods G H, G′ H′, &c., having their centre of motion outside the shaft and on the side C, will not tend to shorten the arms of the lever M A, M′ A′, &c., as long as these are attracted by C; but when they are carried to the opposite side, these rods will draw to them the sheaths and the wheels A, A′, A″, &c., thus shortening the arms of the lever. At the same moment that this shortening is completely effected a current will be sent by the commutator into the electro-magnets O, O′, O″, &c., which will then be in contact with their armatures I, I′, &c.; then the

arms of the lever M A, M A′, &c., will be sustained at their minimum length till the wheels A, A′, &c., shall again reach the electro-magnet E. At this moment the commutator breaks the current in the electro-magnets O, O′, &c., and sends it again into the magnets E, E′, &c., which again lengthen the arms of the lever M A, M A′, &c. It is to enable the rods G H, G′ H′, &c., to extend themselves when the spokes M A, M A′ approach the electro-magnets E, E′, &c., that a slit was adapted to the pivoting of the rods G H, G′ H′, &c., to the sliding pieces of the wheels A, A′, &c. It is needless to say that all the actions of which we have just spoken are successive and repeated for each of the wheels A, A′, A″, &c. It follows that when one of these wheels no longer acts to turn the motor, there are always two more behind to exercise their action.

IV. LOCOMOTIVE APPARATUS.

From the year 1851 we ourselves had an idea of running on a rod, composed alternately of magnetised and non-magnetised parts, an arrangement of bobbins so disposed as to be successively attracted by the magnetic parts of the rod one after another. For this purpose the bobbins, which were three in number, were supported on rollers to facilitate their movement, and carried a commutator, which only sent the current through one or another of them when the attractive action of the coils on the magnetised pieces of the line could be efficiently utilised. The description of this apparatus was published in

the first edition of a pamphlet on electromotors, which came out in 1852, and the apparatus was constructed by Breton Brothers; but the results were so indifferent that we have not mentioned this invention in our other publications. Nevertheless, this plan was taken up again in 1864 by Bonelli, with the idea of realising the transport of heavy things by means of electricity, which was, however, also in the mind of the original inventor when he first conceived this idea. To obtain this result, Bonelli established between the starting-point and the destination a cylindrical tube, divided in sections and provided with coils throughout the whole length of its course. Inside this tube a coil of metal wire, smaller in diameter than the hollow of the tube, received a progressive impulse from the electro-dynamic attraction exercised by the magnetised sections of the tube on the movable coil through which the same current flowed.

Since this, several inventors, among them Militzer, Bellet and Rouvre, Gaiffe, &c., have tried to solve the same problem by so arranging the elements as to constitute a veritable railway with an electro-magnetic locomotive moving on it. We shall now only describe the different arrangements which have been proposed in this line up to the time of the discovery of the reversibility of induction machines, reserving for description in the second part of this work the more important ones devised by Siemens, Deprez, &c.

Militzer's Electro-magnetic Locomotive.—The follow-

ing is the description given of this apparatus by Count Marschall, in the report which he sent to 'Les Mondes' of May 31st, 1866, of one of the meetings of the Vienna Académie des Sciences in 1865:—

"Twelve small horse-shoe electro-magnets are fixed vertically to the arms of a six-pointed star, so that the lines joining their poles should be in the direction of the arms, the polar faces being directed alternately towards the two sides of the common base. The whole system rests on an axis which passes freely through its centre, and on a small guiding wheel. The plane of the star serving as a base for the electro-magnets is vertical with the horizon, and the two ends of this axis are permanently fixed to two wheels, of which the spokes are the electro-magnets. When one-half of these electro-magnets is excited by the electric current, the corresponding armatures are attracted laterally, and the wheels, as also their common axis, revolve until the armatures are opposite their corresponding magnets, and the whole system moves along the rails fitted for this purpose. This movement complete, a commutator fitted to the axis breaks the current in the six first electro-magnets and sends it into the six others, so that a fresh movement in the same direction takes place. The current is furnished by a generator whose poles are in communication with the rails. Every part of the apparatus is properly insulated, so that the passage of the electricity from one line of rails to the other can only take place through the coils of the electro-magnets." It will easily be seen that this

apparatus is nothing more nor less than an electric locomotive, and we shall see that it is not so simple as some we shall have to describe.

Bellet and Rouvre's Electric Locomotive.—This motor, constructed in 1864, and intended by its authors for postal purposes, is described in the following manner by Cazin, in 'Les Mondes' of Dec. 15th, 1864:—

"On two iron rails runs a waggon carrying the correspondence in a box; the two hind wheels are copper, and each carries twenty equidistant horseshoe electro-magnets. They are fixed radially, and their polar extremities are made flush with the tyre of the wheel, so that the rail acts as a continuous armature for all the electro-magnets as they revolve. To start the machine, the current must be sent into the bobbin nearest the rail; its core is then attracted by the rail, and the wheel turns. The attractive force increases very rapidly as the distance between the magnet and the rail decreases, and it attains its maximum on contact. At this instant the circuit must be opened and the current sent into the following one; the successive make and break of the circuit is accomplished by means of a commutator fixed on the axle of the driving-wheels, and formed of an insulated metal ring and an insulating disc, having on its circumference twenty metal plates for distributing the current. The ring slides on a spring, to which is fixed one of the conductors, and the distributing disc is held by another spring in contact with the other conductor from the battery. To each

metal plate on this disc is soldered the end of the wire from one of the electro-magnets, and the other end is soldered to the insulated ring, so that the circuit is complete when there is contact between one of the plates of the disc and the spring. The same ring serves for both wheels, but each has its distributing wheel, and as the metal plates in the one are opposite the spaces in the other, the current is only in one electro-magnet at a time, first on one side and then on the other. And the electro-magnets of one wheel are opposite the intervals in the other, so that there is an attraction for every fortieth of a turn of the wheel.

"The battery may be carried by the locomotive, but the inventors prefer a fixed battery, on account of the difficulty of management of a number of batteries and the cost of conveyance of a considerable amount of dead weight, and also to avoid the proximity of the battery to the correspondence. Therefore, between the rails are laid two wires, on which run metal rollers communicating with the spring of the commutator. These two wires lead to the battery, and it is evident that to stop the locomotive it is only necessary to open the circuit."

Gaiffe's Locomotive.—This is nothing more than a motor of the class of direct rotary movement machines, and the armatures act on a cogged wheel by means of a frame oscillating from right to left and from left to right, by means of two pivoted levers which support it. This frame carries two catches which act on the cogs of the wheel and turn it one

tooth for every movement of the frame between the electro-magnets. The commutator, as in all such machines, is fixed on the axle of the driving wheels. An arrangement in the oscillating frame enables the direction of the current to be changed, and it is automatically worked when the locomotive arrives at the end of its course on the little model line of rails.

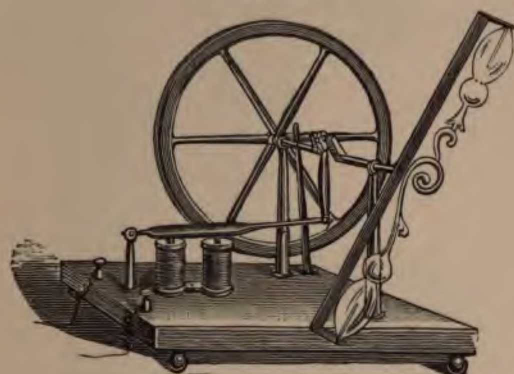
CHAPTER IV.

SPECIAL APPLICATIONS OF ELECTROMOTORS.

SMALL motors have long been employed, as we have already mentioned, in certain scientific experiments where a rapid movement with comparatively little force was required, and more lately in certain industries, such as sewing machines, wire-drawing, silk or cotton wire-covering machines, lathes, and instruments of precision. They have also been employed to drive boats, to work mechanical organs and pianos, and some telegraphic machinery, also in experiments in optics or acoustics, among others the rotation of Geissler tubes, which, with the arrangement shown in Fig. 54, produce very remarkable luminous effects; and beyond the application that has been made of them to boats, balloons, tricycles, pianos, &c., as we shall show in the second part of this work, Trouvé has applied them with advantage to work chronograph cylinders, gyroscopes, artificial breathing machines, revolving mirrors for measuring the speed of light; he has also used them in certain chemical and mechanical industries, such as mixing, drilling, sawing, or plaiting; and by employing them of very diminutive size, and making them perform sundry operations, he constructed

electric jewelry and curiosities, which at one time attracted a great deal of attention. But one of the best-known applications of these motors is that of Edison's electric pen. In this apparatus, shown in Fig. 55, the mechanical action to be effected consists solely in giving to a needle a very rapid and very short to-and-fro movement; the motor is reduced to its most

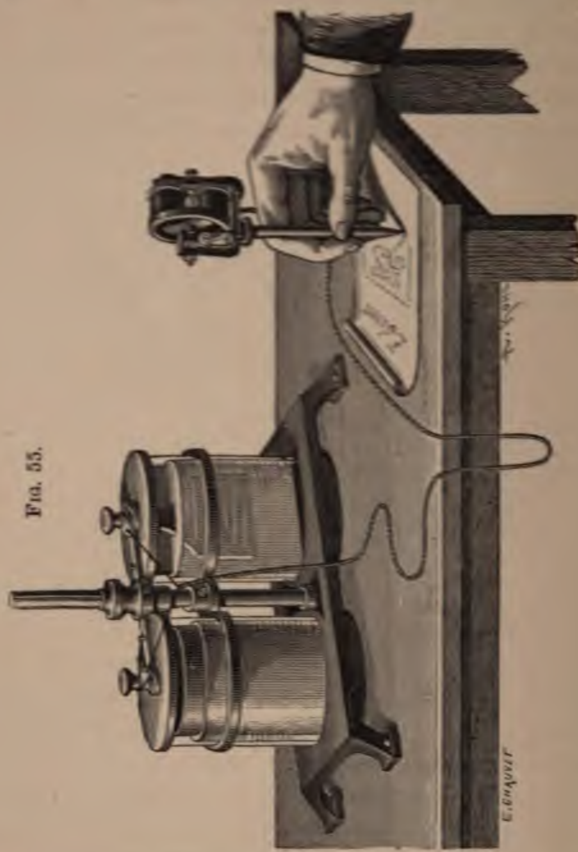
FIG. 54.



simple expression and to very small dimensions. It is, in fact, fitted to the upper part of a sort of pencil-case, and does not occupy with its mechanism more than 4 × 4 × 2 centimetres. It consists of a small electro-magnet, before the poles of which is a horizontal axis pivoting on points, and to which a bar of iron, forming the diameter of a little fly-wheel, is fixed, and this axis is also furnished with a cam which acts on grooves in the support of the perforating needle. Besides this cam is a double eccentric,

which, acting on a contact spring, separates and approaches it to a fixed button forming contact when

FIG. 55.



the armature corresponds with the axial line of the electro-magnet, and also when it is at right angles.

The perforating needle traverses the holder, and only protrudes beyond it a quarter of a millimetre when it is at its furthest. The little strokes of the needle perforate the paper written on, and by working the pen with two Fowler bichromate of potash cells, its speed is so great that the lines traced by the point of the pen appear as continuous lines.

Everyone, however, knows the Edison pen, and there is no need to describe its manner of use; the perforated paper serves to make as many copies as may be desired of the writing or drawing by means of inking the back, and putting it in a press, when the ink is forced through the holes.

We shall see in the second part of this work that recently these little motors have been much more utilised on account of the greater force that has been obtained from them, and it is certain that their use will spread more and more. In the meantime, we will describe some interesting applications which have been made in experimenting instruments of precision by Paul Lacour of Copenhagen, and by M. Trouvé.

Paul Lacour's Electro-magnetic Syren.—The little direct-acting rotary motors already described gave M. Paul Lacour of Copenhagen the opportunity of constructing a little instrument very remarkable for its uniformity of movement, which has been employed with advantage as regulator in certain instruments of precision. The wheel in question is nothing more than a small electromotor so arranged that, being actuated by electric vibrations resulting from

an electric tuning-fork or pitch-reed, it acquires a movement as uniform as the vibrations of the reed itself, and cannot be affected by exterior action, unless such action is strong enough to stop it altogether. Fig. 56 shows this instrument in its simplest form. As may be seen, it is a soft-iron cogged wheel movable round its axis, and before which is fixed a straight electro-magnet, one of the poles of which

FIG. 56.

acts on the teeth of the wheel without touching them, in a similar manner to other direct rotary motors.

If through this electro-magnet are sent a series of currents at equal intervals, regulated by the electric reed, its action on the teeth of the wheel will be a series of attractions, which will maintain an original movement communicated to the wheel, and render it completely uniform when this speed is such that the wheel will for each current travel a distance coinciding with the space between two consecutive teeth. Such currents are sent through an electric pitch reed, of which we give an illustration in Fig. 57, and the

manner in which the two instruments are coupled up with the battery is shown in Fig. 58.

In order to understand the action of this appa-

FIG. 57.

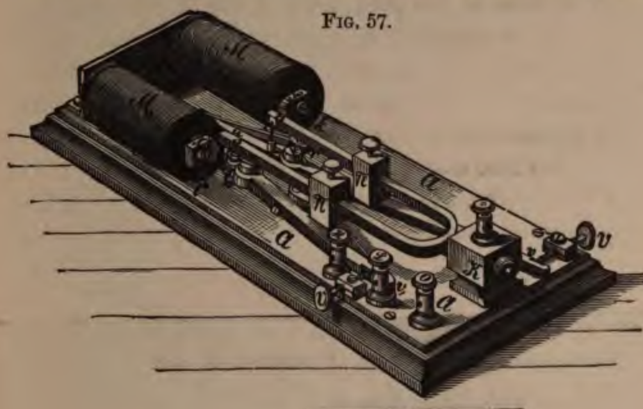


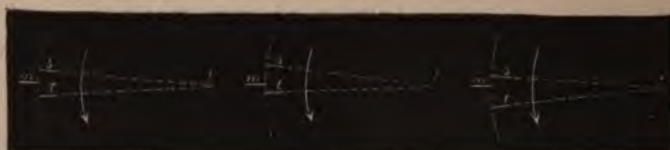
FIG. 58.

ratus, let us see what takes place when one tooth of the wheel passes before the electro-magnet which

actuates it, and we will suppose that the radius of this wheel, passing through the teeth, is represented by the lines *r s*, *r t* (Fig. 59), the mark *m* indicating the position of the polar axis of the electro-magnet. Then let us consider what takes place when the pole *m* is presented in the middle of the tooth, what when in front, and what when behind; these three cases are represented in Figs. 59, 60, and 61.

In the first case (Fig. 59), the action being equal on both sides, the wheel will be in a state of stable equilibrium, and its speed will not be affected by the

FIG. 59. FIG. 60. FIG. 61.



magnet; but this will not be the case in the two other positions, for, in that shown in Fig. 60 an acceleration will result from the action of the magnet which will tend to make the line *r s* coincide with its axis; and in that shown in Fig. 61 there would be an action tending to make the wheel go more slowly.

It will happen then, that if the teeth successively arrive at *s* (Fig. 59) at the moment when the attraction commences, the speed of the wheel will, owing to the intermittent attractions, be subject to a variation during each wave, but the mean speed of the wheel will not be varied, and altogether the wheel

will be, during its movement, in a state of equilibrium with respect to the intermittent attractions.

The position that the wheel will occupy at any moment in this movable equilibrium will evidently be a multiple of the periods, and it may be shown that such is the case by slightly quickening or slacking the speed of the wheel. If it is lightly held back, the acceleration due to attraction will counterbalance it, and the speed at *t* will then be greater than at *s*. If, on the other hand, the wheel is pushed forward, the retarding action will again counterbalance it, and the speed at *t* will then be less than at *s*. There will thus be complete compensation, and, since any small deviation, communicated to the wheel in any way, is compensated and rendered *nil*, owing to the intermittent attractions, the mobile equilibrium of which we have spoken constitutes in fact a stable equilibrium.

"Experiment," says Paul Lacour, "confirms this theory. If a vibrating reed is made to send a corresponding undulating current through the electro-magnet of such a wheel as in Fig. 58, this wheel, having once received a movement which makes one tooth per wave pass before the electro-magnet, will preserve a uniform movement, analogous in many respects to the movement of the wheel when one tooth is continuously attracted by the pole, or, in other words, in actual repose.

"If the wheel is thus in motion, and an external force tends to separate it a little from the proper position of mobile equilibrium, the phono-electric

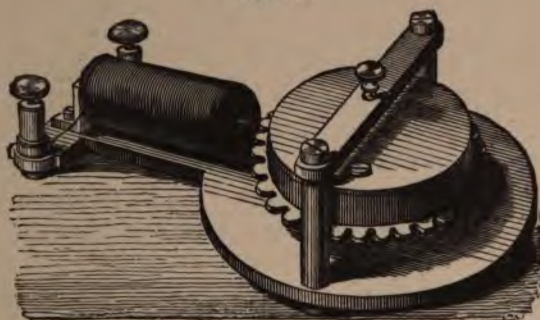
current tends to set it right. But if this disturbing force remains constant, the wheel, although preserving its speed, will find another position of equilibrium, which will depend on the value of the force and its direction. And it is this absolute regularity of speed, notwithstanding slight external forces acting upon it, which allows of its advantageous application in chronographs, and in instruments requiring synchronous movements. These forces must not, however, exceed a certain limit, for the wheel only turns under the influence of a force represented by the difference between sm and st, which may at the utmost reach $+ st$ or $- st$, and if the external force exceeds this value the equilibrium will be destroyed, and the speed of the wheel will be accelerated or retarded according to the direction of this external force.

"Besides this regular movement, there are certain other speeds at which the wheel may be in equilibrium and remain so. Thus, if the wheel turn with exactly half the speed, so that one tooth passes before the electro-magnet for each two waves of the phono-electric current, the relation of the teeth to each alternate wave will be the same as in the last instance, and this will maintain the stability of the equilibrium.

"Similar considerations may apply to other speeds, and it may be concluded in a general manner that this wheel may be rotated at speeds which are the nearest multiples and sub-multiples of its regulated speed. In consequence, this movement may be obtained with speeds equal to $\frac{2}{3}$ or $\frac{3}{2}$ of that of the

normal speed." A regular movement free from variation may be obtained by fitting to the upper surface of it a wooden cup filled with mercury, as shown in Fig. 62. The effect of this weight is not

Fig. 62.



merely an increase in the inertia of the whole wheel, but by the oscillations of the mercury greater regularity is ensured.

Electro-magnetic Gyroscope.—M. Trouvé has very ingeniously applied his annular motor to Foucault's gyroscope, with the object of maintaining its movement long enough to show clearly the rotation of the earth. The revolving sphere is formed of eight straight electro-magnets joined by their bases to a common cylinder. This wheel is then filled in with a mass of insulating material, and covered by electrolytic action with a deposit of copper. When accurately adjusted on its axis, and the poles of the electro-magnets bared, it is fitted inside the electro-magnetic ring, which is suspended from a cross-beam

and supplied with a commutator. The sphere thus rotates in a vertical plane, and being revolved for a considerable time, cannot, owing to the rotation, alter its relative position in space; but the beam will have moved through a certain angle from the movement of the earth, and this angle will show the distance the earth has revolved in the time. Great accuracy and precision are of course necessary in such instruments, and this has been obtained in the two constructed by M. Trouvé, one of which was presented by him to the South Kensington Museum.

The contacts had, of course, in such an apparatus, to be specially designed to allow of the movement of the support, and not of the revolving parts; and M. Trouvé constructed a very ingenious arrangement of platinum contacts dipping into mercury, which answered the purpose very thoroughly. It might have been feared that the magnetism of the earth would have a prejudicial effect on the accuracy of the instrument, but, owing to the exterior poles of the electro-magnets being all of the same name, and acting on the iron hoop simultaneously at each end of the diameter, there was no north and south line, and the apparatus was always in a perfect state of equilibrium as regards the terrestrial magnetism.

CHAPTER V.

ELECTRO-CHEMICAL MOTORS.

THE idea of applying the expansive force of explosive gas to drive an engine is an old one. Huyghens, it will be remembered, thought to utilise gunpowder for this purpose, and in this case the engine would have been arranged almost in the same manner as in the early attempts at steam-engines. It was in perfecting Huyghens's idea that Papin was led to the discovery of the steam-engine. However, the dangers that might have resulted from the employment of such an explosive power for a long time hindered the development of these motors, in which, besides, the igniting arrangements had never been satisfactorily managed. When the heating effects of electricity became known, several inventors again took up Huyghens's idea, employing as an explosive compound not powder, but hydrogen gas mixed with atmospheric air or oxygen, and by igniting it with the electric spark, or with currents sufficiently powerful to make a wire red-hot. Thirty years ago the papers made a great noise about a machine of this kind, invented by Dr. Carrosio, of Genoa, and in 1852 some papers described an electro-chemical motor of M. Moeff, which appeared to have been

well designed, and is said to have given very good results. However, it was only in 1860 that this description of motor was brought into practical shape by Lenoir, and for a long time it was employed very advantageously in certain industries. It was only when the Otto gas-engines made their appearance that it was abandoned, because it was not so economical. However, as faithful historians, we must describe this engine, which for some time was so well known. It is shown in Fig. 63, and Figs. 64 and 65 give details of the mechanism.

The general appearance of the engine is that of a horizontal steam-engine. The cylinder is placed horizontally on a cast-iron bed-plate fixed to a brick foundation, and the piston-rod works between two guide plates. On the shaft is fitted a fly-wheel and driving-pulley. The piston and slide-valves alone are of peculiar arrangement, on account of the electric element. Watt's centrifugal governor is used, and the heavy and cumbrous generator necessary in steam-engines is dispensed with.

The gas, mixed with air in the proportion of eight or ten to a hundred, reaches the cylinder by the tube E (Fig. 63), and the distributing reservoirs R R (Figs. 64 and 65), which are opened at the proper moment by slide-valves worked by the eccentric seen in the cut. Two conductors for the production of the electric spark inside the cylinder, consisting of simple platinum wires fixed in insulating blocks, are shown at I and I′ at the two interior extremities of the cylinder, and are in connection with the

secondary coil of a Ruhmkorff bobbin excited by two Bunsen cells, which, by means of the commutator M attached to the eccentric rod, produce a series of

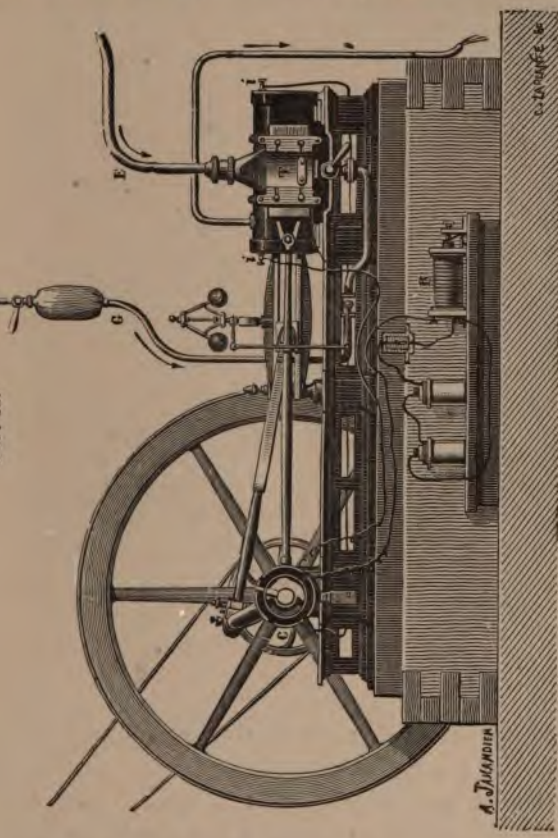
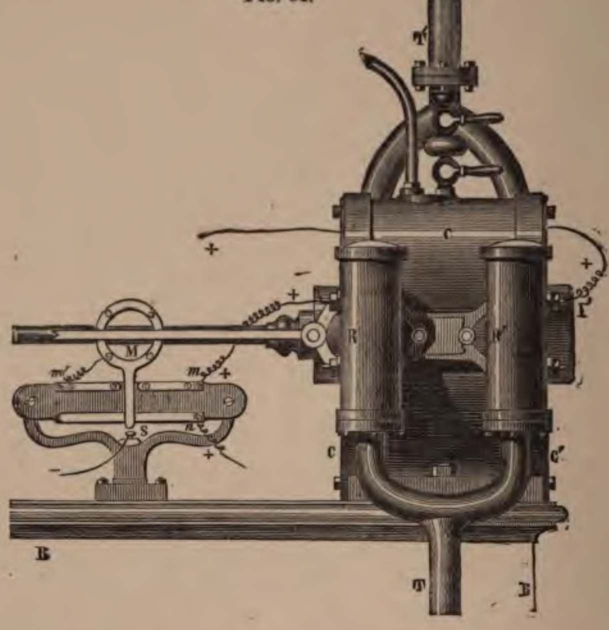


Fig. 63.

sparks when the piston P, having arrived at the end of its stroke, is ready to start in the opposite direction

when driven by the expansion of the gas admitted into the cylinder. On account of the necessity of producing the spark in this manner, the induction coil could not be fitted with a trembler, and the com-

Fig. 64.



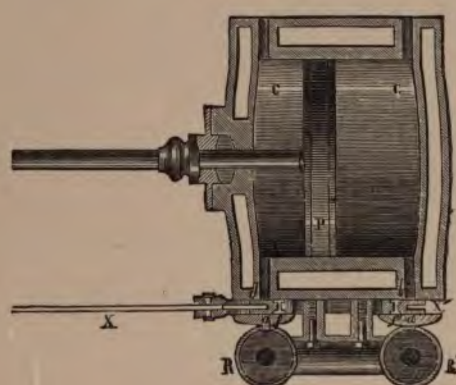
mutator was so arranged that a single spark was given at the right moment.

Under the influence of the spark, the hydrogen combines with the oxygen of the air to form water, and the temperature produced by the combination expands the rest of the gaseous mixture; as this

takes place alternately on each side of the piston, a to-and-fro movement is obtained, which is transformed into circular movement as in ordinary engines. Each time the piston arrives at the end of its stroke, the gas which has done its work escapes from the cylinder by the tube T, in communication with the outer air.

This engine can be started at once, and is also

FIG. 65.



stopped as easily, which makes it extremely useful in small industries.

One of the disadvantages of the engine is the development of a great amount of heat in the interior of the chamber, which would entail the nipping and distortion of the movable parts, if it were not cooled from the exterior. This is effected by a layer of cold water, which is made to circulate round the

cylinder inside a jacket, and this layer of water flows away and is automatically renewed when it becomes too hot. In the latest patterns of this engine the Bunsen battery was advantageously replaced by a Clamond thermo-electric battery, fed, as also the motor itself, by ordinary lighting gas.

END OF FIRST PART.

SECOND PART.

SECOND PHASE OF ELECTRIC MOTORS.

CHAPTER I.

REVERSIBLE MACHINES.

As we have seen, the discoveries with respect to electric motors adapted to produce mechanical work by electricity have been, as far as we have gone, almost restricted to the application of a single principle: the attraction of a soft-iron armature by an electro-magnet or a solenoid. It was natural to begin thus; the movement thus produced, which is the basis of telegraphy, was till then the only one obtained by electricity, and it was certainly a mechanical work, very feeble, it is true, but still mathematically appreciable. Of course the first idea was to increase this work, to multiply it in such a way as to be able to get appreciable mechanical work, commonly called force. We have seen the reason of non-success in this line.

But while clever and persevering, though unfruitful, attempts were made in this direction, another

principle was gradually developing, and was being applied in more and more ways, and it was this by which success was at length achieved.

This property was called induction by Faraday, who discovered it in 1832, and this is how it is shown. Take a magnet, and a conducting wire connected at its two ends with an ordinary galvanometer; this wire thus forms a closed circuit in communication with no electricity whatever, and the galvanometer shows no sign of any electric current in this condition; but take the wire near to one of the poles of the magnet, and the galvanometer shows a current during the time the wire is in motion towards the magnet; stop the wire, and the current disappears; move it away, and a new current in the opposite direction takes place, but stops directly the wire is again still.

An electric current can therefore always be thus obtained by moving the wire before a magnet. We must, however, come to particulars a little: theoretically, this will take place at any distance; in reality, the action is much more feeble at a distance, and for induction currents to be sensible the wire should be brought as near as possible to the magnetic pole. The space in which the pole of a magnet shows its influence is called the magnetic field of the pole. A magnetic action is frequently considered without connecting it with any particular source, and we speak of a magnetic field without specifying the magnetising cause. This may vary from another reason: it is known in fact that magnetic action may

be produced by permanent magnets, by electro-magnets, or even by currents; these different causes may form a magnetic field and give rise to inductions which may be utilised.

It may be imagined what interest this principle presents: it gives the means of obtaining an electric current by displacing a wire in certain fixed conditions—that is to say, by a movement; it involves, then, the direct transformation of movement, or, in other words, of force, into electricity.

It will be interesting to trace how machines have grown out of Faraday's experiment. We have seen how this consisted in obtaining a current of short duration by passing a conducting-wire across the range, or what we have called the magnetic field, of the pole of a magnet. To make a machine from this we must find out the way to make this motion continuous and frequent, and to collect the currents; we should thus have an almost instantaneous succession of currents, which together might be likened to a continuous electric production, if the movements succeed each other with sufficient rapidity.

Further, it is as well to pass as long a portion of the wire as possible in the magnetic field, Faraday having shown that the longer the wire submitted to the magnetic action the more energetic this action will be: which is easily understood, the magnetic field acting at once on all parts of the wire. At length Faraday discovered that the effects were considerably augmented if the wires submitted to the magnetic action, called the induced wires, were wound on pieces

of soft iron, of which the magnetic reactions served to strengthen those of the inductors.

We are thus led to arrange this closed circuit in the form of a bobbin of wire wound on an iron core, and the inductive action will be developed by passing this bobbin as rapidly and as often as possible before the pole of a magnet, which is the inductor. Thus the most simple means, and that which has been adopted from the first, is to mount the bobbin on a rapidly revolving axis, which in its rotation traverses the magnetic field.

These principles were applied in the well-known machine of Pixii, invented about 1832, a very short time after Faraday's discoveries. It was simply the application of the idea given above — a magnet turned before two fixed bobbins, this rather inconvenient arrangement doubtless being employed by the inventor because he did not very well know how to collect the current of the bobbins while they were turning. Clarke's machine soon replaced it; in this two bobbins turned before a magnet, and the current was collected by springs rubbing on metal cylinders. This ingenious, and at that time new arrangement, also served another purpose. We have said that when a wire traversed a magnetic field there were developed in it two currents, the first in one direction on approaching the magnetic pole, the other in the opposite direction when leaving it. The machines we have just mentioned thus give a series of currents in opposite directions, succeeding each other rapidly and alternately; therefore machines of this class are

called alternating. In Clarke's machine, mentioned above, the movable piece, to which are fastened the rubbing springs which carry off the current, is arranged in such a way as to sort out these contrary currents, and put them right in the exterior circuit.

The start being thus given, this type of machine, called magneto-electric, went on developing step by step by accumulating and multiplying similar parts. Instead of putting two bobbins on an axis, several were arranged in a circle; instead of a single magnetic pole, there were used as many as there were bobbins. A greater or less number of similar systems to the first were then placed together on the same axis; and thus was formed, by a series of improvements, the first machine furnishing industrial results, that called the Alliance, which is still in use in the lighthouses of La Hève, and which received its present form about 1856. It should be said that by this multiplication of coils it had been necessary to give up the commutator of Clarke; these machines, therefore, remained alternating.

Some time after the invention of these machines an important improvement began to be introduced; it consisted in replacing the magnets, till then employed as inductors, by electro-magnets. It is known that these can give much more power than the others, only it seems at first sight as if an inevitable complication is thus introduced: for if we wish to make use of electro-magnets, we must have a current to produce them; we shall then be obliged to have one current already in order to obtain a more powerful one. We

shall see directly by what a singular and unexpected turn this difficulty was overcome, which was at first considered insurmountable. Wilde's machine, invented about 1864, consisted of two machines, one on the top of the other: the one had a permanent magnet as inductor, which sent a current into wires wound on iron plates; these became large and powerful magnets, serving as inductors for the second machine, which furnished the useful current. During the time which elapsed before the production of this machine, the induced organ (formerly composed, as we have said, of numerous bobbins placed side by side) had been simplified and reduced to a single long bobbin called by the name of its inventor, Siemens' bobbin. This form is shown further on (Fig. 69).

Soon after there appeared at the Exhibition of 1867 a very curious machine, that of Ladd. In this apparatus two induced bobbins were placed between two iron plates, one at each end; one of the bobbins in turning sent a current into wires wound on these iron plates, as in the first part of Wilde's machine; these plates became magnetised, and the second bobbin furnished a current for use.

Here we are immediately struck with an apparent absurdity. How does it happen that the first bobbin, when it begins to turn, can produce a current? It must have an inductor—a magnet—and it has none, for its duty is to make one; it is its current which has to create the magnet, and this cannot take place if the magnet does not exist. There is a mistake somewhere, it is true, and yet the machine works.

This is because no iron is absolutely devoid of magnetisation; however little it may have, it suffices to give the first bobbin an inductive action, and to create a current. It is at first very feeble, but as it is employed to reinforce the magnetisation it soon augments, and the action increases as far as the limits of the motive force. This curious and fertile principle is not due to Ladd: it was enunciated nearly at the same time by Wheatstone and Siemens; however, although the official priority has been attributed to Siemens, it will be seen from a provisional patent taken out by Hjorth in 1854 that this arrangement was very clearly described by him. This patent bears the title, "An Improved Magneto-Electric Battery." *

Thus was made the type of machine called dynamo-electric, among which may be classed all the recent patterns and the machines in greatest use, of which the types most worthy of remark till now are those of Gramme and Siemens.

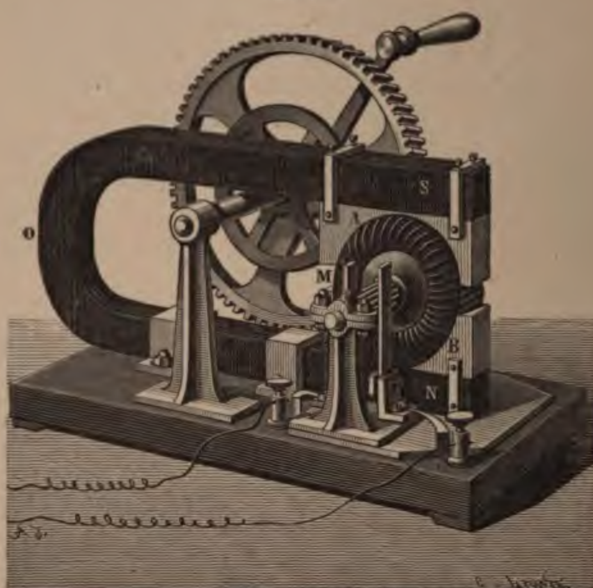
The first originally had the form shown in Fig. 66.

As may be seen, the inductor is a horseshoe magnet O N S. The machine is therefore magneto-electric. The armature has a peculiar form. It is composed of a ring of soft iron, on which is wound the induced wire. This ring is placed on an axis between the two poles of the magnet, which have been fitted with expansions A and B, in order the better to enclose the ring to be induced. The wire

* See the 'Journal of the Society of Telegraph Engineers,' vol. viii. p. 228.

with which the ring is covered is divided into sections, the ends of which are connected to a cylindrical collector M, on which rub two metal springs, or better still, as we have already explained, two metal wire

Fig. 66.

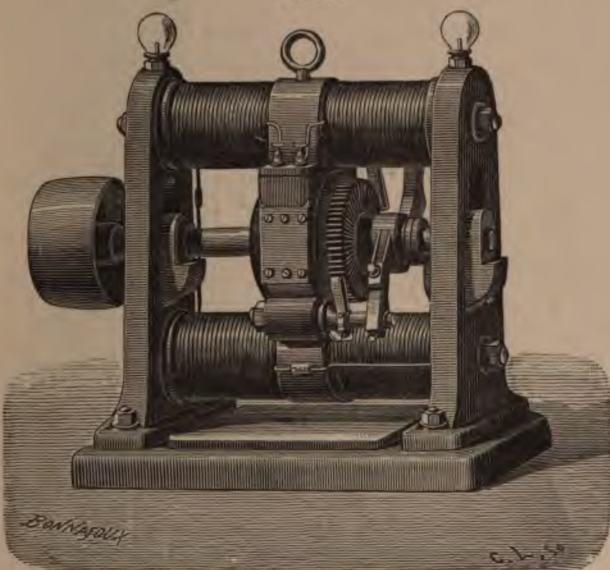


brushes. These brushes receive the current, and send it into the circuit where it may be utilised.

Very soon the improvements we have mentioned were introduced in this apparatus, and it received the form represented in Fig. 67. The bobbin remains the same; it preserves the annular form, which

is the essential characteristic of these machines; the permanent magnet has disappeared, and is replaced by two electro-magnets, which expand round the ring at the poles. The collector and brushes are

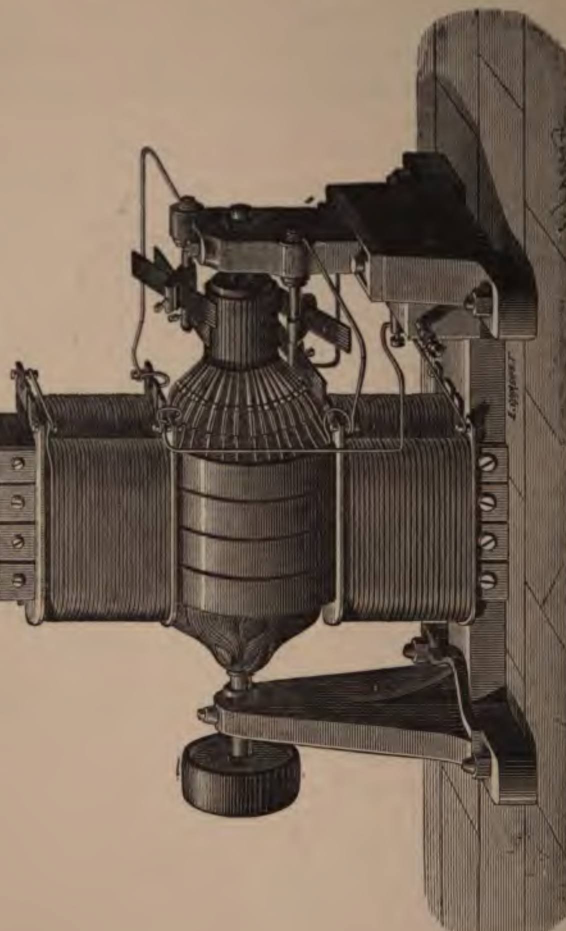
Fig. 67.



not altered; they form part of nearly all recent machines. As we shall see further on, the Gramme machine has undergone alterations, but this is the type most frequently used.

Siemens' machine differs from the above in the form of its armature. As may be seen from Fig. 68, this is no longer in the form of a ring; it is more

FIG. 68.



like a cylinder, on which the wires are wound lengthwise parallel to its axis; the rotation of this cylinder thus brings them successively into the magnetic fields of two electro-magnets, placed one above the other, below the armature; they are sometimes placed horizontally, one on each side. The coils are, as in Gramme's machine, arranged in sections communicating with each other, and also with a collector, seen on the right of the figure, on which the brushes rub.

We have thought it necessary to give rather a long description of these machines, because they are so often met with in electric applications. Besides, it is desirable that they should be understood by the reader, being, as we shall see, the principal agents for the production and transport of force by electricity.

The reader may ask where we are going to wander to? this work professes to be about machines for producing movement, and this chapter has been so far about machines for producing electricity. The two results are not so different as might be believed. On the contrary, they are closely connected by reason of a remarkable property possessed by the machines of which we are speaking. Till now we have supposed that we expend force in turning our movable conductor in the magnetic field, and by this means we get electricity. Now let us do the reverse, send electricity into our movable ring, and we shall see it immediately put in motion and rotate rapidly. If we place on the axis of the ring a pulley with belt

or gearing, we shall be able to utilise this rotation, and get from it force, or more properly speaking, work. So if, in the little Gramme machine (Fig. 66) we turn the handle, we expend some force, but we get an electric current; if, on the contrary, we send an electric current into the machine by means of any apparatus, a battery for example, we shall expend our electric current, but the ring will be put in movement, the handle will turn, and we shall be able to utilise this rotation and obtain work. Machines of this sort may thus be utilised in two ways, and this striking property has received the well-chosen name of reversibility.

The experiment made in 1873 with Gramme's machine at the Vienna Exhibition, is often quoted as the first application of this important principle. One of these machines was set in motion by a steam-engine; it sent a current into a similar machine at a distance of about 500 metres, which was in turn set in motion, and this rotation was employed to work a pump. This experiment is indeed very interesting, and we may admit that it was the first in which the reversibility of machines was employed to furnish a mechanical work of any importance, but it was not the first exhibition of this fertile principle. It had already been perceived, especially by Messrs. Siemens Brothers in 1867; but it had been enunciated still earlier with great clearness and vigour by Pacinotti. This eminent scientist, in advance of his epoch, had, as we have seen earlier in this book, invented about 1861, and published in 1864, a

machine in which were applied and well utilised most of the principles, and even some of the arrangements of detail, which eight or ten years afterwards caused the success of other machines. The attention of the public was not yet attracted in this direction, and Pacinotti's invention was little known till the Electrical Exhibition of 1881 brought it to light, and caused the inventor's merit to be recognised and justly rewarded with a diploma of honour. Pacinotti's machine is given in Fig. 44; it may be seen that he had discovered the ring arrangement of the conducting-wire in which the current is developed, and had thus constructed the movable bobbin now called a ring-armature. Two electro-magnets E E′ formed the inductor, and we would again refer the reader to the remarkable sentence quoted at page 80, with which he ends his paper describing the apparatus.

This is the enunciation of the principle of reversibility, and it is the earliest known; therefore the honour of having first clearly perceived this scientific fact belongs to the learned Italian. This historical incident is interesting, from the importance of the principle which it involves. It is not indeed peculiar to electric machines, it is a very general property, as was seen at once as soon as attention was drawn in this direction. Nearly all phenomena are theoretically reversible; in giving out heat we produce movement, as for instance in steam-engines. But everyone knows that by movement we get heat: for example, if we rub two bodies

together they get hot, and the work used in the movement is represented by the heat produced; the phenomena are so closely allied, that it is possible to determine what quantity of heat corresponds to a given amount of work, and this is called the mechanical equivalent of heat. By giving out heat certain chemical decompositions may be effected, but if it is possible to reunite the bodies of which the elements have thus been separated, the same amount of heat will be generated in the process of reunion as was necessary to separate them. Reversibility is thus a very common property; it cannot always be utilised, but electric phenomena are among those in which it is most easily shown, and where it is generally susceptible of application. It is because induction machines possess it in the highest degree, that they have become the means for the production and transport of mechanical work by electricity.

One important remark must be made here: originally electric motors really produced force, they were set in motion by the current of an electric battery, zinc was expended in the battery, labour was gained from the motor. It was real development of mechanical energy. With induction machines it could doubtless be the same; however, it is not thus we work. The current of the battery being dear, and difficult to produce, we want to get electricity from the machines themselves, and they produce this by expending labour. We thus absorb labour in order to recover it. It may be asked, what is the benefit of such an operation? It lies in the

transport. We can imagine many cases in which transport is of the first importance. How many waterfalls, for instance, now useless because of their situation, would be priceless if they could be transported near to a populous centre! The amount of force thus neglected is immense, and electric transport furnishes the means of adding this to human power. Let us consider too, the enormous number of cases where power might be applied to scattered machinery or tools. Imagine, for instance, the cranes along a quay: in the ordinary way a special engine is necessary for each; with electricity a single engine might easily be used to work them all. A still more important consideration is that of the sub-division of force. As we shall see further on, the hope is just now established that by means of electricity it will be possible, not only to transport power, but also to divide and distribute it. We will not here dwell upon the importance of this, which must be considered separately; we only wish to point out to what consequences electric transport of power may lead. Besides, the reader may take note of its importance, seeing in the following chapters the successive development of the applications to which it has already led.

CHAPTER II.

GENERAL REMARKS ON MODERN MOTORS.

WITHOUT inquiring further into the working of the machines we are considering, we may see at once why these apparatus have achieved the success till then vainly sought for, and whence comes their superiority to those which have been described in the first part of this book. We have already touched upon this question in the first part, but it will not be amiss to revert to it. In the old machines movement was produced by magnetising one or more masses of iron and making them attract movable armatures, whose displacement produced mechanical work; it was of course necessary that the magnetised masses should cease their action as soon as the attraction was complete, in order to recommence it again so as to give a fresh impulse. This system has three grave defects: 1st, magnetic actions are rapidly weakened by distance, so that, the attractions of a magnet only exercising force in a very small radius, the impulses obtained can be strong only in a very small part of the movement; 2ndly, the motion thus obtained is the result, not of continuous action, but of a succession of jerks, which is always a defective mechanical means of obtaining labour;

3rdly, and this is the greatest disadvantage, the magnetisation and demagnetisation of masses of iron of any size cannot be effected instantaneously: they require a time, very short indeed, but still appreciable; besides, these alternations do not take place without a considerable loss of force. It will be easy to give one experiment in proof of this. An electro-magnet being rapidly and frequently magnetised and demagnetised, the core is heated perceptibly; this heat represents so much work, it is the force lost in the successive magnetic movements given to the mass of iron. Yet this expression is erroneous, for force is never lost, only transformed; only here a part of the force employed, instead of furnishing the magnetisation required, produced heat not required of it, which means a loss of power in the useful work in hand.

These three disadvantages are avoided, as may easily be understood, in induction machines. In this sort of apparatus: 1st, the distance of action is reduced to a minimum, the armature turning at a very short distance from the magnetic poles; 2ndly, the action, though not theoretically continuous, is composed of such a rapid succession of impulses that it is practically so; and 3rdly, the magnet producing the magnetic field which gives rise to the induction remains always in the same state and goes through no alternations, which allows it to be magnetised to a far greater degree of intensity than in the old machines. There are also other advantages possessed by these machines.

Having recognised this superiority, we must now look a little more closely into the manner in which dynamo-electric machines transport force and produce work.

Let us first recapitulate some general ideas.

When we examine any source of electricity intended to produce a current, the first element to be ascertained is that called the electromotive force, i. e. the force with which this source tends to urge the electricity along. In the same way, if we wish to find the mechanical value of a waterfall, we must first know the height of the fall and the pressure its column of water is capable of exerting; again, if we wish to value the work to be got from a steam-boiler, we must first know what is the pressure of the steam. These relative elements for such different producers of force are however so similar, that in electricity we use the terms electromotive force, tension, and pressure almost synonymously and indifferently.

In the case of a battery, the E. M. F. once determined depends on the nature of the battery, the number of elements, and their arrangement. In generating machines the E. M. F. depends on the construction of the machine, and also on the speed at which it is driven, increasing with the latter. This force cannot be determined without ascertaining at the same time the speed given to the machine. These data are also not sufficient, for the E. M. F. of the machine is influenced besides by exterior conditions.

The E. M. F. of a generator being known, the

current that it will furnish depends on the circuit; in the same way as a fall of water will give a result depending first upon the height, but also upon the diameter and the length of the tubes through which it has to run: so that any electric source gives a current in proportion to its electromotive force and the resistance of the circuit. It must never be forgotten that in this circuit must be reckoned not only the wires and the apparatus in the exterior circuit, but also the generator itself; for the current flows through that as much as the rest, and the resistance it opposes to the passage of the electricity is always a necessary element, and sometimes a very important one, to consider.

These three elements, then—the electromotive force E, the intensity of the current I, the total resistance of the circuit R—bear a very simple relation to each other, and it is written $I = \frac{E}{R}$, these quantities being reckoned by the units adopted by the recent Congress of Electricians, namely, E in volts, from the name of Volta; R in ohms, from the name of the scientist who gave the above formula, and I in ampères, from the name of the great French philosopher.

Let us return to the machines. Take for example a Gramme machine of the ordinary type represented above. We connect it to a motor, a steam-engine for example, and it is rotated; we give it a speed, determined and constant, say 1000 revolutions per minute. First, we will put no wires between the ter-

minals, the circuit is open; under these conditions there is no current, but also no work expended to turn the machine. Of course a little is required to overcome the friction, but it is very little, and we may take no notice of it. Let us now join the two bobbins by a long wire of 50 metres for example, and at the same time an instrument to measure the current. It will show a very weak current, and the steam-engine will begin to do some work; if we shorten the length of the wire the current will increase, and with it the work expended by the engine, and these two quantities will go on thus increasing as the resistance of the circuit is diminished. It will be asked, what becomes of the work produced by the steam-engine? We shall very quickly see, if we push the experiment too far. The metal circuit, the machine itself, and the instruments would become dangerously heated, and if we are not careful the whole thing might be burnt up; the work is turned into heat.

Now, instead of this circuit simply closed with a wire, let us couple up with our machine another similar one, leaving in the wires our instrument to measure the current. To begin with, we will fix the second machine so that it cannot turn. We shall then find a powerful current, and the steam-engine will expend considerable power; our second machine in this case only acts as a conductor, and as it has a low resistance, the actions produced are intense. It would even be difficult to try the experiment, or at least to give it any duration, for the two machines

would be in great danger of burning, the whole of the work being turned into heat; we reap no advantage, in fact, as the other machine is fixed.

Let us now liberate the machine and have it completely free. This is what we shall see: the machine is at once put in movement, and its rotation is very rapidly accelerated; at the same time the current meter shows that the current decreases very rapidly, and at the end of a moment this current becomes and remains completely nil. If, now, we test the speed of the second machine, we shall find it identically the same as that of the first. The steam-engine then gives no work, things remain as if the first machine had its circuit open; it must not be forgotten that under these conditions the second machine also is doing no work.

What is happening? To understand it, it must be remembered that a dynamo-electric machine turning with a closed circuit always produces a current, so that when our second machine began to turn it began to produce a current. If we consider carefully, we shall see that this current will be in an opposite direction to that which it receives. The two machines then tend to send into the same circuit two contrary currents; they mutually destroy themselves, and the difference between them is all that is apparent; but when the two machines go at the same speed, the two currents which tend to develop are equal, and they cancel one another completely. In reality, there is no electric current in the circuit: the machines turn as if the circuit were open.

Let us now put some work on our second machine, say a weight to lift. The functions of the two machines are now quite distinct. The first machine generates electricity—this will be the generator; the other gives us work—this will be the motor. We see immediately what happens. The motor, having work to perform, goes slower; it cannot maintain a speed equal to that of the generator. Then the counter current given off will not be equal to the direct current; this will cease to be counterbalanced, a current resulting from the difference will flow, and will be indicated by the current meter; and it must be well understood that if the work put on the motor is small, it will only be slowed a little. The difference between the speeds of the two machines will be slight, and therefore that of the two currents, so that the actual current will also be small. If, on the other hand, the work is great, the slackening of speed will be considerable, and the great difference in the electromotive forces will give rise to a powerful current, so that there is a necessary relation between the work put upon the motive machine and the current in the circuit. By increasing this work we slow the motor more and more, the current is constantly increasing, and we come in fact to the point whence we started; the motor, too heavily laden, will stop, and the current will reach its maximum, as we saw in the first instance.

In all this, what work have we obtained? At first, the motor being free, we got none; at last, the machine being loaded till it stopped, we had none

either. It is thus seen that the work obtained depends on two things: first, on the work accomplished at each turn; and secondly, on the number of these turns; for in increasing the energy and the work in turn the machine is slowed; that is to say, the number of turns is diminished. There must be a maximum. There is one, in fact, which is, when the speed of the motor is equal to half that of the generator; we then obtain from the second machine the half of the work expended in the first, and we obtain from it the greatest work it can give.

This brings us to an important consideration. We see that the work obtained is never equal to that expended; there is always a loss. The proportion between the two works—in precise terms, the ratio of work obtained to that expended—gives the proportion of loss. This is what is called the return. It cannot be equal to 1, and we have just seen that in the case where we endeavour to obtain the maximum work it is $\frac{1}{2}$. This proportion is not necessary; by not requiring the greatest work that can be furnished the amount will be diminished, it is true, but with a better result; that is to say, with a more advantageous return. We shall see how we shall have to work when practical applications of importance are undertaken, which will certainly be very shortly, but we are only beginning at present. Suppose, for example, that it is desired to transmit and receive electrically work equal to 5 horse-power. We may employ as generator a machine capable of absorbing 10 horse-power; a similar machine employed at the

other end under its maximum conditions will give the 5 horse-power required. We should then have a return equal to $\frac{1}{2}$; but we might employ a more powerful generator of higher electromotive force, capable, for instance, of absorbing 15 horse-power. Such a machine employed as a motor would give the five horse-power with a work of say only eight horse-power expended (these figures are not intended to be precise, but are only given to fix the ideas), and that because, not being pushed to its maximum, it is capable of a more advantageous return. It is true that an arrangement of this kind would necessitate a greater original expense, but in exchange it would entail a daily saving of expense. This is not at all an exceptional arrangement; how are steam-engines used to burn a small amount of coal for a given work? Expansion engines are used, but it is well known that these engines would give much more power if the full pressure of steam were used. We do not ask from them all they are capable of doing in order that the result may be obtained under its most favourable conditions; the first outlay is increased in order to reduce the working expense. This will certainly have to be done in the mechanical employment of electric machines, in order to increase the return. We shall return to this point hereafter.

Before leaving our two machines, we will try another experiment. Just now, the generator maintaining the same speed, we put on the receiver work constantly increasing, and we saw the current increase from zero to the greatest possible for the resistance

of the circuit. We will now try the reverse. The receiving machine will have a constant work to perform—at each turn it will do the same work; whereas the generator we will drive at varying speeds, the galvanometer being left in the circuit.

This, then, is what happens. The generator at first going slowly, a feeble current is shown; the receiver does not stir. As we increase the speed the current increases; for a certain value I of this current, the motor starts. From this moment, although the speed of the generator increases, the current does not; only the speed of the motor increases at the same time as the other, and in proportion to it. As to the work obtained, it naturally increases with the speed of the motor.

We see what takes place: as long as the current produced is not enough to overcome the weight put on the motor, it cannot move; it is then only an inert resistance in the circuit. When the current becomes just sufficient to overcome this weight, it begins to turn, and at the same time begins to produce a counter electromotive force. If the receiving current increases, it becomes too powerful for the weight to overcome, and the motor moves fast; but then the counter electromotive force increases also, till the increase of current is exactly counterbalanced, and its value reduced to that which is just sufficient to overcome the weight.

This law may be demonstrated otherwise, by giving to the generator a constant speed, and placing a constant weight on the motor, but varying the resist-

ances between them; we may also arrive at a current which cannot be varied, whatever may be the resistances, provided that the receiving machine is able to turn; its speed alone varies.

We have already stated this fact, that there is a necessary proportion between the work put on a machine and the current which it receives; but we may complete it by this important remark, that this proportion is absolutely independent of the speed, and obtains whatever may be the movement of the machine. This law is of fundamental importance, and we shall have to recur to it in the course of these studies.

CHAPTER III.

MODERN SMALL MOTORS.

HAVING rapidly examined the nature of the machines which will serve for the transmission of force, and taken account of their mode of action, it will be natural to follow up the chain of experiments by which we have arrived at the results obtained up to the present time, and to see something of the forms of machines in use.

This is the method which we will follow; but before going further it is necessary to treat once for all an accessory subject which will embarrass the logical development of this history. At the same time, as machines intended to transmit large forces, we meet with, in fact, a number of apparatus destined to produce and transmit small forces; that is to say, fór light work, with a limit of about 10 kilogrammetres per second. Although their invention was later than that of large machines, we may attach them to the more ancient form. These, as we have seen, were motors susceptible of great precision, but capable only of very small work. The motors of which we will now treat are in a similar position, but with a very much enlarged field. It will therefore be well to study now this group of motors. One

question is immediately met? How is it that there are special small motors, and why cannot they be made of the ordinary type, but reduced in size? It is that this construction would be very difficult and costly. Dynamo-electric machines contain parts where very delicate work is required, such, for instance, as the winding of the wires on the revolving bobbins or rings. Below certain dimensions the construction of these would be almost impossible, and besides, these machines contain parts which in large ones are already pretty small, and they would become microscopic in a machine very much reduced in size. There are also electric reasons; that is to say, that the proportional reduction of a large machine would

Fig. 69.

generate in turning, or, on the other hand, would necessitate to turn, currents not in proportion to the larger machine. From all this it will be seen that a small motor must be a different apparatus to a large one.

The oldest of these motors, and that which has given the type to nearly all the others, is that of M. Marcel Deprez.

Since 1854 a particular bobbin due to Dr. Siemens, of which the above is a representation, has been in existence. It is composed, as may be seen, of a

cylinder of soft iron, on which the wires are wound lengthwise. For this purpose two longitudinal grooves are hollowed in the cylinder, in which the wires are laid. When a current flows through these coils, the bobbin becomes a magnet which presents two long polar faces, and the position of these poles changes with the direction of the current. With this bobbin and permanent magnets Siemens had a magneto-electric generator. We have said that this bobbin was employed in a great number of machines, among others those of Wilde and Ladd.

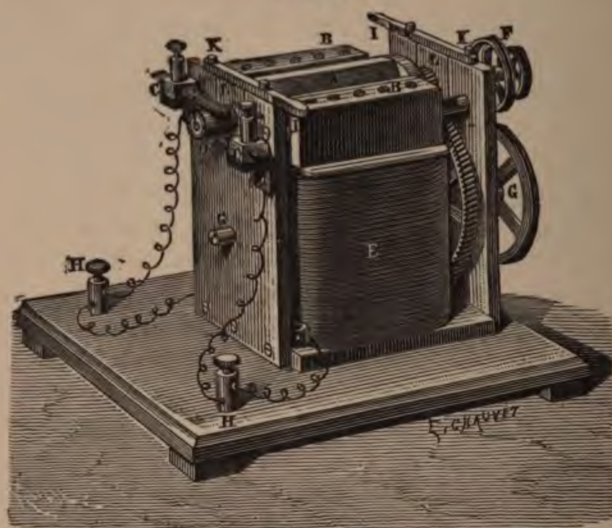
Marcel Deprez was the first to show that these machines were reversible, and could be made good electromotors. It is not impossible that this fact had been vaguely seen by some, particularly by the Messrs. Siemens, but they did not see in it anything of importance. The reader is well aware that it is not he who first notices a phenomenon who is the inventor, but he who recognizes the value of it, and draws advantage from it; nearly all scientific facts have been seen and even discussed before they were utilised. He who discovers a thing anew, and makes a machine of it, is the real inventor.

However, Ladd's machine, as it was, was only a bad motor. Deprez modified it, took away the metal expansions of the poles, adjusted the position of the brushes, and obtained the form shown in Fig. 70.

It will be understood how such a machine works. When an exterior current is sent into it, it magnetises the soft-iron plates B B and the revolving bobbin A. It is arranged so that each of the poles B

repels the pole of the bobbin opposite to it, which then begins to move; after making half a turn, the brushes C C supplying the current, having remained stationary whilst the bobbin turned, are now in re-

FIG. 70.



versed position; the current enters in the opposite direction, and the poles are reversed. The repulsion is thus renewed, and the bobbin continues to revolve. The movement may be utilised either by the wheel G, or by means of K or F, according to the speed required.

This form of machine is not M. Marcel Deprez's latest; he thought it better to make use of perma-

nent magnets, thus approaching the first arrangement adopted by Dr. Siemens, but he gave it a different form by fixing the bobbin between and parallel with

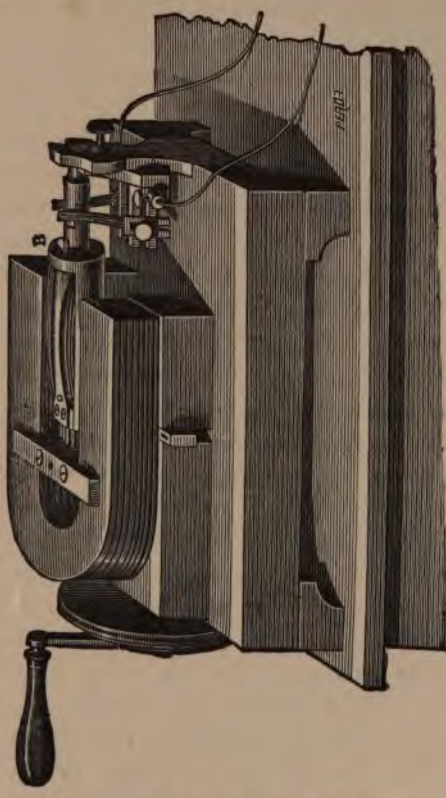


Fig. 71.

the arms of a horse-shoe magnet. All the magnetism of the magnet is thus utilised in a very complete manner.

The form of the machine will be seen from Fig. 71. The current enters by two small brushes, seen on the right. In the arrangement shown, the apparatus has a grooved wheel, so that it can be used as a motor, and a handle to use it as a generator. The weight of the machine is not more than 4 or 5 kilogrammes.

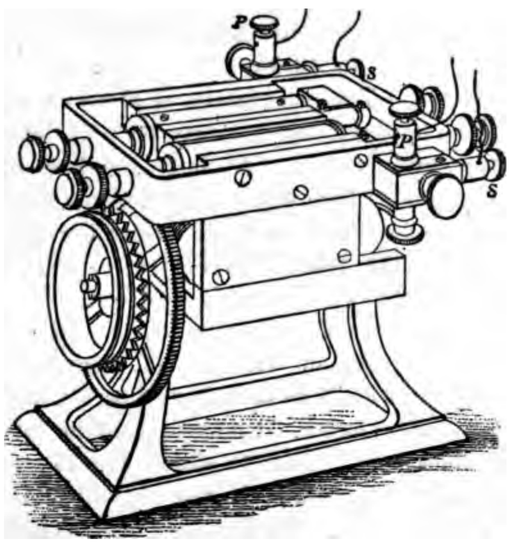
Remarking that in Ladd's machine transformed into a motor, the production of the magnetic field entails a loss of energy equal to about one third of that absorbed by that of the whole machine, Deprez considered that, as we have said above, he would gain by doing away with the electro-magnet and replacing it by a permanent one. Dynamometer indications, together with measurements of the zinc consumed, showed in fact that with an electro-magnet as inductor, the work obtained from the consumption of a kilogramme of zinc was from 70,000 to 90,000 kilogrammetres, while it varied from 90,000 to 130,000 kilogrammetres when a permanent magnet was used. The latter also had the advantage of being used as a generator, but, on the other hand, it necessitated a somewhat heavy apparatus compared to the work produced. In practice also a serious obstacle was encountered. The magnet lost its magnetism very rapidly, and to avoid this Deprez had to return to the original arrangement, but in a somewhat altered manner and with very much reduced dimensions. In his new model, in fact, the space occupied is not more than 6 centimetres in width and 7 in length, and the

electro-magnets are doubled. It is composed of two small electro-magnets of 5 centimetres, each with opposite poles presented, and between these poles are the Siemens armatures of 2 centimetres in length and 16 millimetres in diameter. They are arranged on the same horizontal axis, and at right angles one to the other: that is to say, that when one is between the poles of its electro-magnet the other is perpendicular to its magnet. As this motor revolves very rapidly, the driving pulley is reduced in speed in the proportion of 1 to 40 by means of a pinion and cogged wheel. The commutator is also so arranged that three distinct currents may be sent into the inductors and bobbins. As it is the base of the electro-magnets which forms the bed of the machine, it will be understood how well devised the arrangement is for the production of the greatest force possible with the smallest weight of iron.

After the preceding motors comes in chronological order that of Trouvé. It resembles the Ladd-Deprez, as will be seen from Fig. 72, and is a dynamo-electric motor. It however contains interesting modifications. That to which Trouvé attaches the greatest importance, is the alteration in the shape of the bobbin. The Siemens bobbin employed by Deprez is cylindrical, it is therefore always at the same distance from the poles; that of Trouvé presents a section representing two half spirals, so that in its rotation the iron approaches the pole, and moves rapidily away from it when the current is reversed. This arrangement we have already

described at page 115, and Trouvé therefore avoids a disadvantage. In the preceding motors it is necessary to start the bobbin or at least to move it a little, as without that the poles would be exactly opposite one another and would not start, being at the "dead point" as it is called. Trouvé's arrangement enables this defect to be lessened. The spiral form

FIG. 72.



is besides very slightly marked, and an increase of one millimetre is sufficient to obtain the effect sought. It may be remarked also that the winding of the electro-magnet has a particular form; instead of winding the wire on the two arms, as in the Ladd-Deprez machine, there is only one coil on the soft

iron forming the base which joins the two arms. The size of the apparatus is thus reduced.

From the experiments of d'Arsonval, it appears that the useful return of this machine is inferior to that of Deprez: that is to say, that the kilogrammetre of force is obtained at a greater expenditure. On the other hand, it must be admitted that for the same weight this motor gives a better result than the former.

We may mention in connection with the preceding,

FIG. 73.

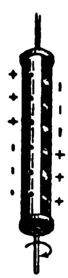
a motor which differs very little from them, namely, that of Cloris Baudet. It is composed of two

FIG. 74.

Siemens bobbins so fixed that the iron bars are at right angles to one another, so as to avoid the dead-

point; two straight electro-magnets embrace this pair of bobbins and give them movement. The form is shown in Figs. 73 and 74. It may be likened to two Ladd-Deprez or Trouvé motors placed end to end. It only differs as regards the bobbin, of which the core, instead of being formed of a single bar, is composed of a series of small cores, each having a separate coil. So that, instead of being a simple armature, it may be considered as a series of small electro-magnets placed close together, and of which the poles are joined by a single bar, as seen in Fig. 75. Figs. 73 and 74 show the arrangement of the whole, and, as will be seen, the electro-magnets are straight, and have their bobbins about the middle of their length; the armatures revolve between the prolonged poles. This little motor has however nothing very original, and has not been much used.

FIG. 75.

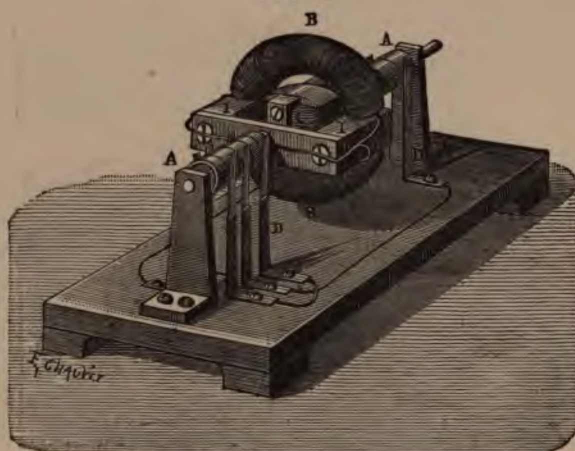


As will be seen, in these little motors inventors have taken into consideration one of the conditions we have mentioned above; the large mass of iron has a constant magnetism, while the alternating magnetisation only takes place in the bobbin, which is of very small mass. Join to that the very high speed of these motors (about 3000 revolutions per minute), which seems a necessary condition of all electric motors, and the advantages will be understood.

It will be interesting to mention one form of motor which M. Deprez has suggested as an experiment.

It is represented in Fig. 76. It consists of a very short Siemens bobbin, and, contrary to the foregoing arrangements, this bobbin is fixed. It is surrounded by an iron hoop B B, with two coils of wire. On the current passing, it renders one half of the ring and of the armature magnetic, and these repel one another.

FIG. 76.

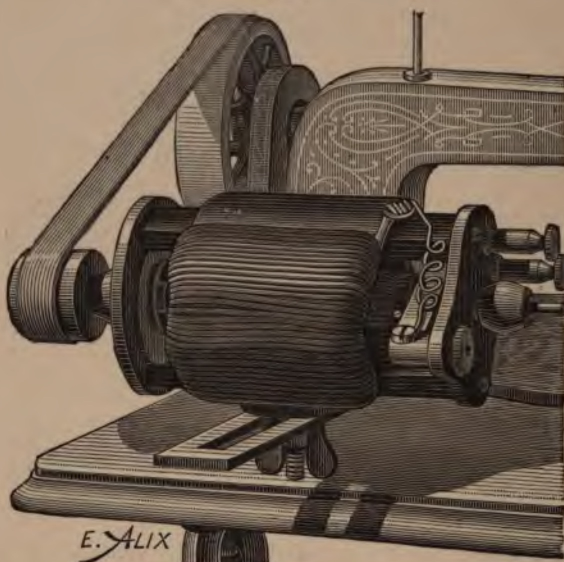


If the armature is fixed and the ring movable, it at once revolves, the brushes which communicate the current being so fixed that the current changes direction at each half turn, and the rotation is continued.

This is wanting in principle; it is in the great mass of iron that the magnetic alternations take place. Therefore, this motor is very inferior to those previously described. We have, however, mentioned it

on account of the singularity of its form and the analogy which it presents to other machines, particularly to an American motor which was noticed at the Exhibition of 1881, invented by Griscom. This is also a dynamo-electric motor. It consists of a

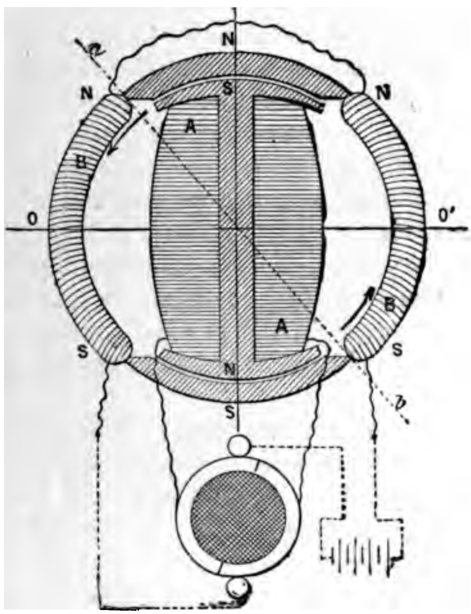
Fig. 77.



Siemens bobbin, but, as will be seen in Figs. 77 and 78, this bobbin is surrounded by a sort of hollow cylinder of soft iron, or more correctly, of malleable casting. This cylinder is wound with two coils, dividing it into two halves, and combined to produce two consequent poles at the two extremities of the same vertical diameter. When the axis of the

bobbin nearly coincides with the line N S of the consequent poles, the current is reversed, and a repulsion is produced at N and an attraction towards S, which spins the movable electro-magnet from one

FIG. 78.



side to the other as the reversal takes place to the left of N S. As will be seen, this motor somewhat resembles the defective arrangement of Deprez mentioned above, only that here it is the bobbin which turns while the ring is fixed. It is therefore

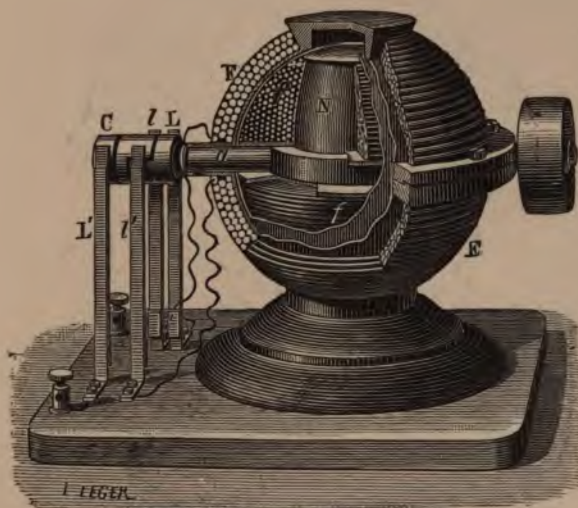
theoretically correct, and this motor has given very satisfactory results. It is very small and light, and its speed very great. We have no precise details of its effective return, but this motor has perhaps been more used than any other. It has been very extensively exhibited, and is very largely used for sewing machines, ventilators, grindstones, knife-cleaning machines, dentists' drills, small lathes, &c. Another little motor which has been a good deal used is that of Messrs. Cuttriss and Co., of Leeds, which has given satisfactory results. It consists of a Siemens armature revolving between the polar extensions of a flat electro-magnet, the magnet and armature being in series.

As will be noticed, all these motors are based on the Siemens armature; they are therefore not induction motors, but magnetic, and in consequence resemble those which have been described in the first part of this work.

Another type of motors must still be considered. We know that if we place a magnetised needle in a frame surrounded by wire, when a current is sent through this wire the needle will turn till it sets itself at right angles with the wire. If we now reverse the current, the needle will return to its original position, continuing the turn—at least, if the reversal of the current were carefully arranged. We may thus obtain a continuous rotation, and, in consequence, work. It is not necessary either that the needle should be a permanent magnet; it may be an electro-magnet.

It is on this principle that the little spherical motor of Burgin is devised. It will be seen from Fig. 79 that he has taken a sphere covered with wire wound round it approximately following the horizontal parallels. Inside is an iron core movable on a horizontal axis, and also covered with wire,

FIG. 79.



forming parallel layers. When the current is turned on, these two sets of coils tend to set themselves parallel; and if the current is reversed just as this position is attained, the movement continues. It will be seen that there is here no variable magnetisation; the part where the currents are reversed is in the

exterior wire. This, then, is a curious principle, and different from the others; but at the same time, the very powerful action of soft iron, when magnetised, is lost. The spherical form adopted by Burgin is also peculiar; it must render the winding of the

Fig. 80.

wire difficult, and it gives to the machine a very strange appearance; the only thing seen is a closed sphere, with an axis protruding, which by a hidden power is rapidly revolved. This motor is a little heavier than the last mentioned, and we have also no information as to its effective return.

Jablochkoff has recently designed a little motor

of ecliptic form, as will be seen by reference to Fig. 80. The movable part is formed by a flat bobbin *b*, placed obliquely on the rotating axis. This bobbin is of iron, and forms also a short electro-magnet. The part fixed is the larger bobbin, B, with framework of copper, fixed obliquely as in the case of the other, but inclined in the opposite direction. The arrangement of the commutator is such that the current traverses the movable bobbin always in the same direction, and that the changes of direction for each half-revolution only take place in the fixed solenoid. The result of the crossing currents in this and the movable bobbin is the revolution of the latter. This motor, as well as the former, has a very original form, and shows that now-a-days everything is done to utilise every kind of dynamic property of electric currents. It has the same objections as the rest; the loss due to residual magnetism is certainly avoided, but the powerful agency thereof is not utilised. It seems to be acknowledged that it is difficult to obtain powerful action without the help of soft iron. These two small motors are feeble, and rather theoretically curious than really useful.

CHAPTER IV.

APPLICATIONS OF SMALL MOTORS.

THE small motors which we have just described have been applied in ways which it will be interesting to mention.

The first which presents itself, and which has already been applied for some time, as will have been seen in the first part of this book, is the working of sewing-machines. It is certain that considerable efforts have been made to practically realise this; for the working of these machines for a length of time by manual power cannot but have regrettable results for women. The various small motors that we have described are very readily adapted to this work; some have been expressly devised for this purpose, notably the Griscom. If this application has not been widespread, it is not the fault of the motor, but rather of the supply of electricity. Powerful batteries are not numerous; they are difficult to handle, and some are dangerous and give off disagreeable fumes. In fact, there is only one which has been effectually employed, and that is the bichromate of potash, but it is difficult to use this for long together. If some day we should have a battery, easily handled, power-

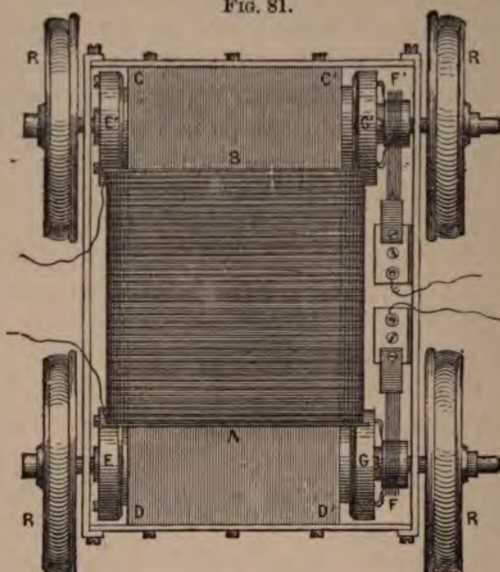
ful, constant, and not wasteful, without doubt this application will be very largely adopted.

At the central telegraph office in Paris the small Deprez motors were for a long time employed to work the distributing apparatus of the Baudot multiple telegraph. This mechanism requires a rapid and constant rotation, with very little work but great regularity; electromotors are readily adapted to this, and among them the magneto-electric motor of Deprez has, besides other advantages, a minimum of tendency to variation. At present this work is done by Humblot's small water turbines; this kind of motor is employed throughout the central Post Office to work the continuous rotary telegraphs.

A very interesting application of electromotors was suggested and tried by Messrs. Deprez and Bontemps in 1880. It was proposed to work by their means the carriage of telegrams instead of by the pneumatic tubes now in use. This system, which has great advantages, has also a great drawback; it will be understood in what it consists. In a cylindrical tube is a little carrier, which is the projectile, and in which are the telegrams; an air-pump produces a vacuum in front of the projectile at the same time that it compresses the air behind it; thus driven by the difference of pressure, the little carrier flies along the tube and arrives at its destination. In this operation, at the same time that the projectile is driven along, the whole column of air in the tube is also driven through it, and this produces considerable friction. The pneumatic transmission of telegrams in

Paris at the present moment absorbs no less than 120 horse-power. The idea of Messrs. Deprez and Bontemps consisted in making a small railway of which the rails would be conductors, a little motor would be arranged as a locomotive as in Fig. 81, of the pattern we have called Ladd-Deprez, that is to say,

Fig. 81.



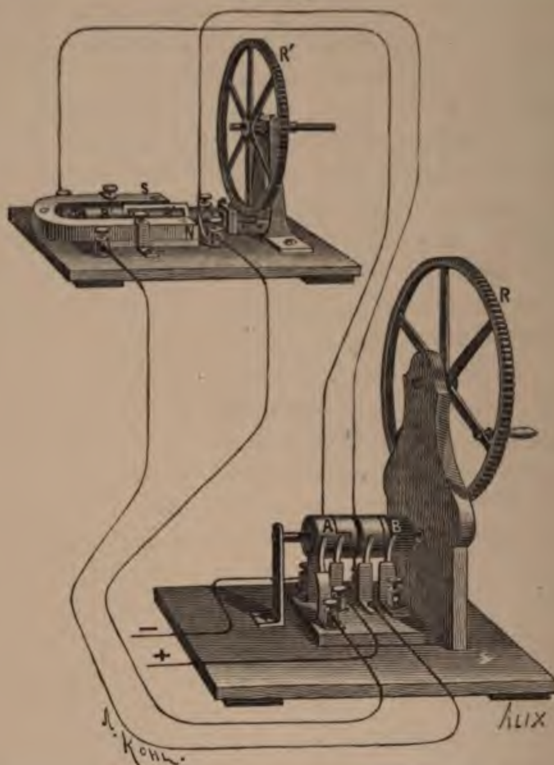
with an electro-magnet, but instead of one bobbin it has two, E G, E^1 G^1, one at each end. These bobbins are directly attached to the wheels, and the current entering from one of the rails through one wheel leaves by the other, in its course rotating the bobbin and thereby the wheels, and thus the machine goes

along. The idea was to build on this locomotive a little box, in which the telegrams or even small parcels might be put. The tube was abandoned and replaced by a small railway, in order to avoid the friction of the air. The trial at the Central Telegraph Office succeeded very well, and, as will be seen further on, a similar experiment was tried in Germany almost at the same time. It was calculated that the despatch of telegrams in this way for Paris would only require 12 horse-power instead of 120, a very important saving. It has however not been adopted. It would have been necessary to change the entire existing plant, and a further powerful reason was that the proposed railway would require a larger passage than the tubes, and what with water-pipes, telegraph and telephone cables, pneumatic tubes, &c., the room taken up by these modern inventions in those subways of Paris, originally destined solely for other purposes, is jealously watched.

M. Marcel Deprez has made another very curious application of his motor. It might be necessary to reproduce at a distance some motion, so that the two were synchronous. You might for instance put up at a departure station a needle on a dial, and at the arrival station a similar one to reproduce the movement of the first, whatever it was, always turning as quickly as it and stopping at the same point. This problem has been solved by means of the Deprez motor. It is slightly modified; instead of one bobbin the motor has two, put end to end; the iron bars of these two bobbins are at right angles, as will be seen

at $A^1 B^1$, Fig. 82. (This arrangement was shown by Deprez before Baudet adopted it for his motor, as will have been already seen.) At the departure station

Fig. 82.



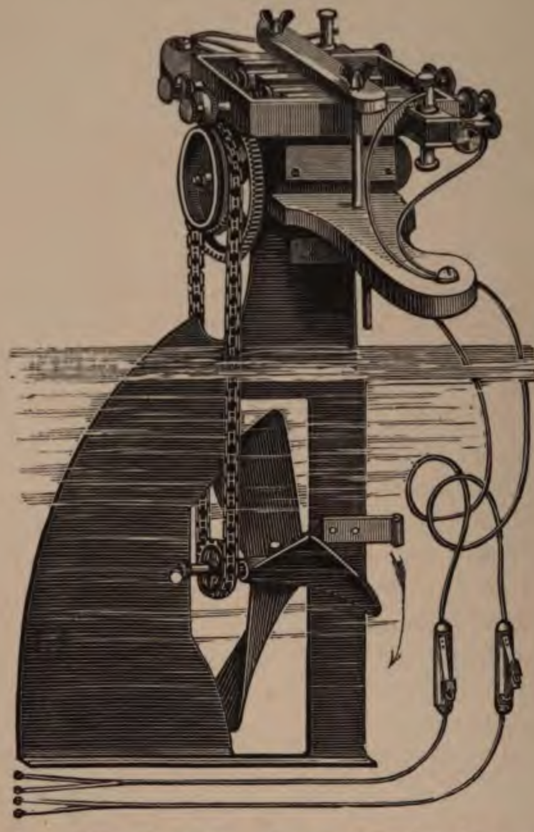
is a sort of commutator A B, sending along the line a series of currents alternately reversed. Theory shows and experiment proves that the motor then

reproduces with perfect exactitude the movements of the commutator, even for the highest speeds.

Trouvé principally endeavoured to apply his motor to locomotion. He constructed before the Exhibition of 1881 an electric velocipede with favourable results; it was less interesting than the boat he put on the Seine, and which was worked on the little lake at the Exhibition. For this he made use of a small double motor, that is to say, two bobbins put close together, fixed on the rudder-head. The movement was communicated by means of an endless chain to a small screw fitted in the rudder itself, which was very handy for steering. The electricity was produced by a bichromate of potash battery in the middle of the boat, and brought to the motor by two flexible cables, which served at the same time for yoke lines. The whole was light and worked well. The general appearance is represented in Fig. 85, and it was possible by this means to go at the rate of $1\frac{1}{2}$ metre per second (about $3\frac{1}{2}$ miles an hour). In the battery used the plates were attached to a small winch, so that they could be raised or lowered into the liquid as desired. The battery therefore was only at work when wanted, and Fig. 84 shows its general arrangement. Trouvé has also constructed other arrangements of this motor, as applied to navigation, and where the boat requires considerable motive power he places the motor in the boat itself, so that it acts directly on the screw shaft. Another application of this same motor was shown at the Exhibition of 1881. It was employed

to work a pianista. A pianista is a sort of mechanical key-board, worked by compressed air, and fixed

FIG. 83.



to an ordinary piano. By feeding the instrument with sheets of card-board pierced with holes, and

passing them through by means of a handle, the apparatus works levers which drop on the notes and perform a tune. The electric motor was employed to turn the handle, which it is rather tedious to work by hand. That which was applied to the pianista in

FIG. 84.

the Exhibition, which we give in Fig. 86, was of such small dimensions that it was able to be fitted to the side of the apparatus without causing any inconvenience, and was very well adapted by Journaux, who has also applied Trouvé's motor to his sewing-machines. The pianista was worked by six Faure

Fig. 85.

accumulators with a small extra battery for grand effects. We need not further enlarge upon this application; it will easily be seen how, in every

Fig. 86.

case in which a regular rotation is required without much force, these little electromotors come in very conveniently. We can imagine many instances of

this description, which there would be no interest in enumerating.

Trouvé has applied his little motor in another curious way. In agricultural countries, particularly those cultivated as pasturage, running water is much used for irrigation. These waters are, of course, very carefully used and divided. Each little stream has, for instance, its day set apart in which it supplies water for use. To bring it to the land requiring irrigation it is necessary to make trenches and dams to raise the level of the water to that of the land. These works are expensive, both to establish and to maintain. Trouvé has employed his little motor to work a chain of buckets which raise the water and replace the dams. Everything being taken into consideration, it does not appear that this means would be less costly than the system of dams, owing chiefly to the heavy expense of the battery; it is, however, original enough to be worth mentioning. Besides, it might be employed in new works, or in urgent cases when the works already established might be out of order.

Usually these little motors have been applied where regular rotation without much force is required, as was the case with the earlier machines, as we have seen in the first part. They have, as we have said, succeeded their predecessors by extending the field of application. It is sufficient to mention chronographs, gyroscopes, Foucault's mirrors, &c., which are advantageously worked by these motors. D'Arsonval has made an interesting application of

the Trouvé motor. In certain physiological observations it is necessary to maintain artificial respiration in the animal under experiment; for this a little bellows moved by water was employed. D'Arsonval found it advantageous to employ electric motors; they are simply connected with the bellows, and give it a regular movement, thus accomplishing the work in complete security.

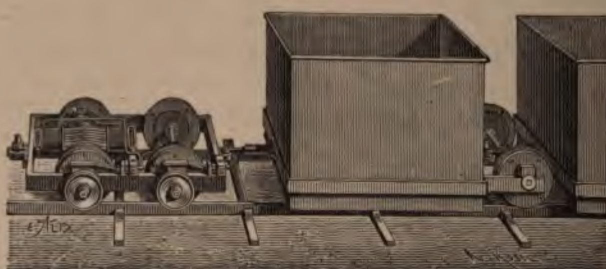
Before quitting the subject of small motors, we must notice some particular types. We have said that usually large machines do not answer if reduced to very small dimensions; this is true, but not infallibly so. Thus, about 1880, an experiment was made by Siemens and Halske to make a small postal railway, worked by Siemens' ordinary machine, of small dimensions.

They made a little locomotive, worked like that described above (p. 196), this last being rather later. The complete apparatus consisted of a model train, with a locomotive and little box-carriages to carry dispatches, as shown in Fig. 87. It was even proposed to convey parcels in this way, which would have been a great convenience. Difficulties similar to those we have already mentioned have put a stop to the final execution of this scheme. The small machine employed differed only in size from Siemens' large machines.

Since the Exhibition two types of motor have been produced, which are taken from the large machines, and hold an intermediate position between the large and small motors. One is due to Meritens,

the other to Gramme. The former has again adopted the Pacinotti ring: that is to say, as seen in Fig. 88, a movable ring formed of coils in distinct sections, separated by small pieces of soft iron. He has made his inductor in the form of a circle, or rather rings of iron wound round, and made so as to constitute two semicircular magnets, as in the Griscom motor described above. He has thus made a simple machine which can be cheaply produced; he also constructed

Fig. 87.



several others, giving from 15 to 50 or 100 kilogram-metres per second. These machines will certainly be much used. One type of these little machines has been provided with gearing, so that it can be set in motion by means of handles turned by four men. It thus furnishes powerful currents for some minutes, and will be most useful in laboratories, giving the means of proving electric experiments without the necessity of maintaining a battery of many elements.

It is the same with the little Gramme motor

shown at the Exhibition, but this has only been in the market since its close.

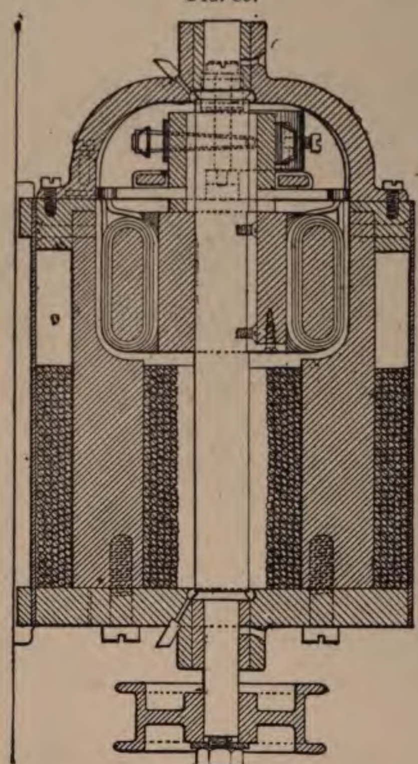
In Fig. 89 is given a section of a slightly modified type of Gramme machine. The ring remains the

FIG. 88.

same, but the inducing electro-magnets are placed on one side only, forming at the same time the framework of the machine. The return of this machine appears to be favourable. It is very compact and elegant in form. The apparatus is very similar to

Pacinotti's machine, and if the reader will refer to that he will see that if the Gramme machine were set on end (as it is figured) it would greatly resemble

Fig. 89.



the early apparatus. Professors Ayrton and Perry have recently designed a new form of motor. They have discovered that for dynamo-machines the

armature should, for good results to be obtained, be small relatively to the field magnets, whereas for motors the reverse should be the case. They therefore make the armature large, in the form of a Gramme ring, and inside it revolve a small field magnet, the axis of which carries the revolving brushes. They also adopt a compound winding of the field magnet, consisting of partly shunt and partly series coils, so that the motor automatically regulates itself. When loaded and when light it runs at about the same speed, this being a great advantage. The motor appears to be very good, and its return high.

We must expect to see other new patterns of these motors produced as soon as we are able to command a convenient source of electricity. As we have said, the electric battery, as it now is, is impracticable when continuous work of any importance is required; it is at the same time expensive, inconstant, and very inconvenient. It will, in all probability, be perfected in time, but it is to be supposed that before that electricity will be made in great quantities by large machines, and given out at different places in small quantities; in a word, we may hope that in the course of the next few years we shall have learnt to distribute electricity. We will refer again to this question hereafter. When this problem shall be completely and practically solved, the small and medium-sized motors we have just described will at once be widely circulated, and we shall doubtless see a great many other patterns appear, to the great advantage of individual labour.

CHAPTER V.

FIRST APPLICATIONS OF TRANSPORT OF FORCE.

We have already mentioned how, at the Vienna Exhibition of 1873, Fontaine and Gramme submitted to the public the first real application of the principle of the reversibility of electric machines, and at the same time the first real example of electric transport of force, by working a pump at the distance of 1 kilometre by means of a gas engine.

This process was but slowly applied: for this there were many reasons. At first the machines generating electricity were few and weak; the rapid growth of this industry, the number of types now in the market, deceive us; but we must not forget that, in 1873, of those now in use, the Gramme machine was the only one then existing, and that was made for special applications, chiefly for electro-plating. Electric lighting was quite in its infancy; the arrangements of machines for this sort of work were not at all suitable for the transport of force, as we shall explain further on.

There was, however, one attempt made in 1877, at the Arsenal of St. Thomas d'Aquin. The officers worked a dividing machine 60 metres away from the motor. This is a transmission which greatly re-

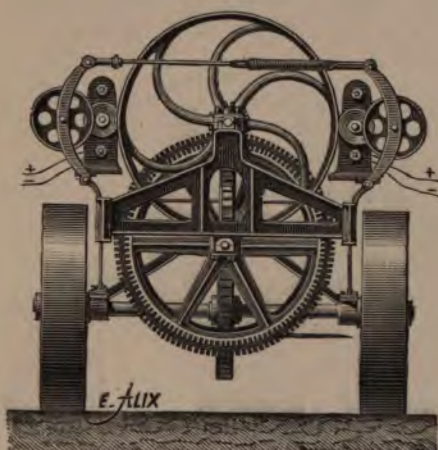
sembles the preceding examples, owing to the smallness of the power transmitted. About 1878 Cadiat, at the Val d'Osne and the Lyons Railway Company, made some attempts of the same sort to work tools; but the most striking application, and the first which was really practical, was made in 1879 by Félix and Chrétien at the sugar-plantation at Sermaize. Extensive public experiments were made, and caused great excitement in the electric world.

The work performed by electricity was ploughing. It is well known that mechanical cultivation, and particularly tillage, is very advantageous; it is at once economical and productive, but presents peculiar difficulties; up to the present traction-engines have been used, carrying cylinders round which is wound a steel chain, which draws a plough with several shares. The result is satisfactory; but these machines are very ponderous, they cannot go everywhere, they necessitate a considerable provision of fuel, and use a great quantity of water—all great disadvantages, and costly to convey to the scene of work. With electricity these requirements disappear. In the experiment at Sermaize, two carts were employed, each weighing 2 tons, instead of 18, like the portable engines; these carts each carried a drum provided with a cable to wind and unwind, and two ordinary Gramme dynamo-electric machines. On an electric current being sent into these machines they were set in motion, and this rotation could be utilised either to turn the wheels of the conveyance, which then began to move along

Fig. 90.

like a traction-engine, or to turn the drum which shortened in the cable, and brought towards it an agricultural apparatus which made furrows like a plough. The electricity produced at the works is conveyed by conducting cables to the machines. Fig. 90 gives a general idea of the work. Of course this system would hardly be applied to such a small piece of ground as that represented in the plate. We

FIG. 91.

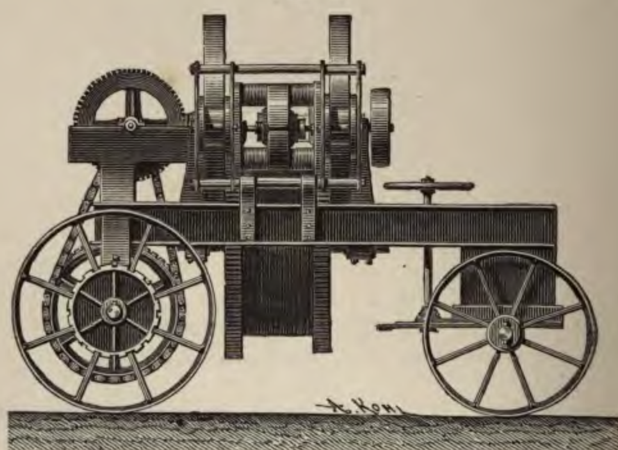


have reduced it to show at a glance the different essential points of the experiment, viz. the works where the electricity is produced, which are seen at the back, and the receptive machines at work at the front of the picture.

We give here drawings of the carts which were used for this operation. Fig. 91 is a front view, in

which the two Gramme machines, which are the motors, are easily distinguishable; they are suspended in some way in a common frame-work, of which the upper piece is a bar with screws, which allows of their pressing on a large pulley between them. We must not, however, forget that these machines rotate very rapidly, making as many as 600 revolutions in a minute; therefore a considerable change must be effected in the movement before we can obtain the powerful effort necessary to move the cable and slowly draw the plough. Fig. 92 is a side view, in

Fig. 92.



which one of the Gramme machines is seen. Beneath the frame-work of the cart is seen part of the drum which carries the cable, and the cog-wheels by means of which it is worked. To the left is seen the arrange-

ment by which the movement is transmitted to the wheels of the cart, and makes of it, when required, an electric locomotive.

It remains to speak of the generating machines which furnish the electricity to these motors. At first ordinary Gramme machines, originally intended for lighting purposes, were used, but it soon became necessary to construct special machines. There were several reasons for this. In the first place, the generators constructed for other purposes were not competent to absorb and transmit a great electric force; it was therefore necessary to have them more powerful. In the second place, these generators furnish force in a very inconvenient way, and we must lay a stress on this point.

If we wish to estimate how much work a waterfall will furnish, we must take two things into account: we will call the quantity of water furnished per second Q, and the height from which it falls H; the quantity of work the fall is capable of producing is thus represented by Q H. In the same way, in calculating the work furnished by a current, we must take two things into account: the quantity of electricity flowing through it, which is called the intensity I, and the force which propels it or the electromotive force E; the work of which the current is capable is therefore represented by the product E I. Looking at the sum total of the work, it is immaterial whether this product be obtained in one way or another; whether E be less and I greater, or the contrary; provided the product remains the same,

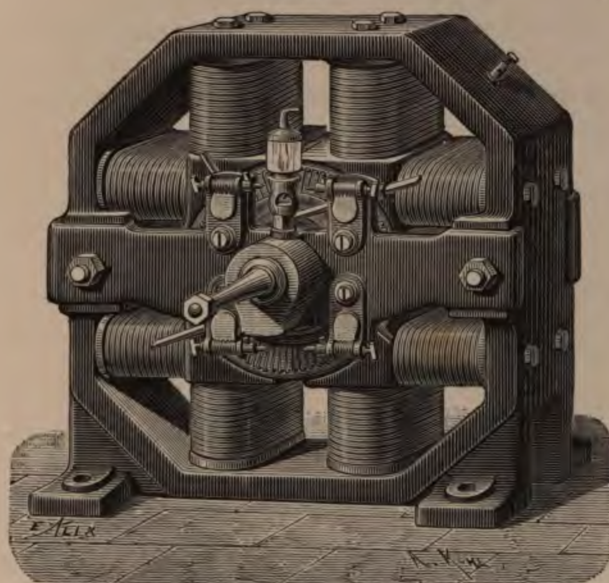
as it would not affect the total work. This, however, does affect it considerably if the force have to be transmitted through a long conducting wire and made use of at a distance, as we shall see.

We have said that in the electric transport of force there is always a loss of some of the work expended; what becomes of this lost energy? If we search for it we shall find it transformed into heat in the conducting wires, and in the machines themselves. The laws of Joule enable us to determine the quantity thus dissipated. If we take R to represent the total resistance of all the wires of the circuit, machines, and conductors, the heat which will be developed in them by the passing of a current with the intensity I will be represented by $R\,I^2$. In the application we are considering all this heat is useless, and is a loss which we want to reduce to a minimum, which leads us to diminish to the smallest possible quantity the intensity I; but then, to preserve the product E I, which represents the total work, at the same value, we must increase the factor E: we are thus led to employ electricity of high pressure.

Although these laws were not elucidated and fixed in 1879, as they have been since, as we shall see, there was already some idea of them; and endeavours were made to produce a type of machine of higher tension than those then in use. There are two ways of doing this. We know that currents are obtained by moving a wire in a magnetic field. Experience proves that the quicker this movement the

higher the tension obtained. The machine should therefore be made to turn as rapidly as possible. On the other hand, the more numerous the passages of the wire across the magnetic field, the more numerous will be the electric impulses which will accumulate for pressure. We are thus led to multiply the number

FIG. 93.



of magnetic fields through which the wire must pass in turning. On these principles Gramme reconstructed his apparatus in the manner represented in Fig. 93. The ring is larger; at first sight there appear to be eight electro-magnets, but we soon see

that they are joined two and two at their extremities, so as to form four magnetic fields. A collector which is not seen in the figure receives the impulses thus produced, and gives higher tension. The potential of the first lighting machines was about 60 to 70 volts; that of these octagonal machines was as high as 250 or 300 volts. We shall soon see that this was only a first step, and that it was necessary to go much further. However, these machines were serviceable, and we shall see more of them in speaking of the Electric Exhibition and the applications which followed it.

CHAPTER VI.

FIRST APPLICATIONS FOR THE LOCOMOTION OF CARRIAGES.

THE application which should best pay, perhaps that in which electricity approaches the nearest to perfection, is the locomotion of vehicles. In all the systems in use up to the present the motive agent itself moves with the conveyance it has to draw: the horse goes before the carriage, the locomotive with the train; and then there is not only the motor itself to move—that is to say, properly speaking, the steam-engine—but the boiler to produce the steam, and the coal to furnish the heat, besides the water; all this causes considerable expenditure of force. Certainly, in contemplating some steam-engines, the wonder is, not that they can draw carriages, but that these enormous engines can be made to move themselves. By making use of electricity, the whole motive power is reduced to the electric motor fitted to the carriage, and which may be very light; the production of the force will take place at a distance, at a fixed centre, where the engines can be arranged as desired without inconvenience. The connection between the fixed generator and the moving motor

may be made to act in several ways, but in no case does it interfere with the locomotion.

The first attempts in this line were, however, quite recent; almost all, as we shall see, being due to the German firm of Siemens and Halske.

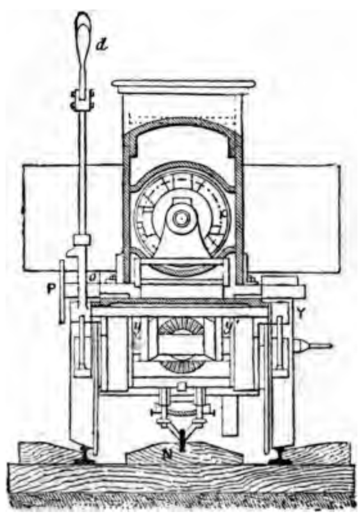
The combination to be applied had nothing complicated; it is the electric transport of force in its most simple form. What is there to do after all? To set the wheels of a carriage in motion. The dynamo-electric machine is eminently fitted for this purpose; for, applied to produce force, it is in the form of an axis endued with the power of turning by itself. It will suffice, then, to set up at the starting-point a dynamo-electric machine driven by a suitable motor which will send a current to a similar machine carried by the vehicle to be moved. The system in itself cannot properly be called an invention, there not being many variations in the execution, at least in the principal parts; there are, however, as we shall see, some difficulties in the carrying out, which have required, after all, no small amount of work and ingenuity.

The first application of this kind we meet with was effected by the firm of Siemens and Halske, at the Berlin Exhibition, during the summer of 1879. It was a small model railway, laid down on a very small scale. The length of the line was about 500 metres; it was in the form of an oval, so that the passengers returned to the starting-point. The train was composed of a small electric locomotive and carriages for the passengers. The latter were small

platforms mounted on low wheels, with two rows of seats facing outwards parallel with the lines. The general appearance of the train was that given in the accompanying Fig. 95.

The locomotive was simply composed of one of Siemens's dynamo-electric machines like that represented in Fig. 68. This was laid horizontally on a framework with wheels; the bobbin was placed parallel to the line, the field electro-magnets being perpendicular thereto. Fig. 94 is a cross-section,

FIG. 94.



and Fig. 96 a longitudinal section of this apparatus. The latter shows a section of the cog-wheels *l*, *t*, *v*, and *x*, by which the rotary movement of the bobbin

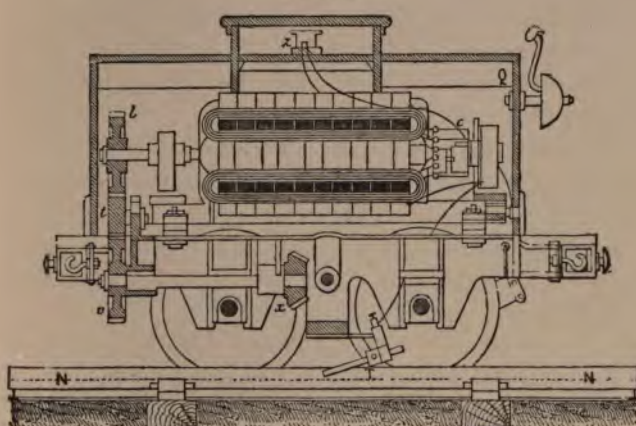
FIG. 95.

was transformed and transmitted to the driving-wheels of the little locomotives; Fig. 94 shows the bevelled wheel *x*, which completed the communication of the movement.

It remains to be seen how the electric current passes from the generating machine.

To introduce the current a bar of iron N (Fig. 94) was laid between the two rails, and encased in wood

FIG. 96.



to insulate it electrically from the soil. On this bar, which ran the whole length of the way, rested two spring rubbers of the locomotive. The current was transmitted by these rubbers into the machine; after having done its work it passed through the wheels of the locomotive and back to the generator by the iron rails. It was not necessary for the rails to be com-

pletely insulated, for if some of the current escaped into the earth it still returned to the generating machine, that being equally connected with the ground.

A lever *d o* served to connect or to interrupt the current, and thus to set the train in motion or to stop it.

This beautiful experiment was a great success, and the little railway was set up successively in other towns, Brussels, Dusseldorf, and Frankfort. In the last-mentioned town it ran from the Exhibition to the railway station, a distance of 250 metres; three miniature tunnels had been erected on its route to make it more picturesque.

More important attempts were to follow this first trial. On the 12th of May, 1881, an electric tramway for real use was inaugurated near Berlin, between Lichterfelde and the Cadet's College, under the superintendence of the same firm, Siemens and Halske.

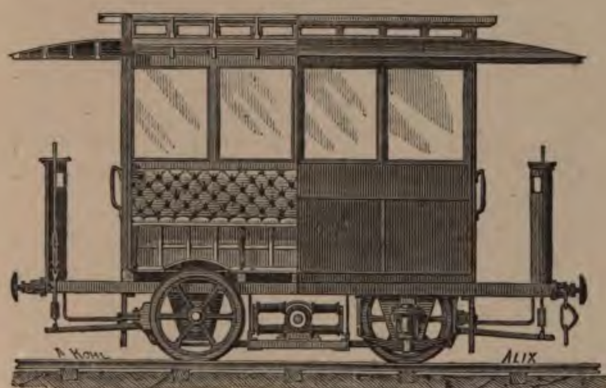
This was not the first project; there was an idea first of establishing an electric tramway in Berlin itself. For many reasons this work was postponed; while waiting for the greater, the lesser work was accomplished.

The length of the line thus laid down is 2450 metres; it is laid on the level except for the slight inequalities necessitated by the declivities of the route. The electric generator was at first composed of two Siemens machines. Of course, this arrangement was only provisional, these machines being

replaced by a single powerful one connected direct to a rotary steam-engine.

The vehicles are, of course, very different from those used in the first experiment; in this case there is no locomotive drawing other carriages. Each vehicle carries its own motor, the carriage being in the form of the trams in use in many large cities, as Paris, Brussels, &c. These carriages are capable of

Fig. 97.



containing twenty-six persons. A representation of them will be found in Figs. 97 and 98. In the first figure may be seen, under the body of the carriage between the wheels, the electromotor, which is, of course, one of Siemens's; the bobbin is placed at right angles to the road. Its movement is transmitted to the wheels by means of a belt working on cylinders outside the wheels, as seen in Fig. 98. The transmission of force is effected here in a much

more simple way than in the preceding arrangement. The carriages are provided with brakes, which may be put on at either end, so that the carriage will run in either direction without being turned round, as with ordinary trams.

There is also under the control of the conductor a means of introducing an artificial resistance, so as to be able to regulate the speed; nevertheless, this is not of very much use, as by a happy property of dynamo-electric machines, the speed, so to speak, regulates itself, and this is rather an important point.

FIG. 98.

In Chapter II. of this second part, which treats of the conditions under which mechanical work is transmitted by means of electricity, we said that when the receptive machine which does the work has to make a great effort, it goes very slowly; it follows that the current from the generating machine, being but slightly resisted, grows in intensity, and furnishes to the motor the means of exercising the necessary effort. If this effort diminishes, the receptive machine goes faster and faster, so as to offer more and more resistance to the passage of the current generated; this grows weaker,

and with it the effort exercised, but the total work effected, nevertheless, increases in proportion to the increase of speed up to a certain maximum.

It is thus with the application of electric force to the locomotion of vehicles. Let us suppose our vehicle stationary on a level road. At the moment of first sending the electric current to set it in motion, we have that special resistance to overcome which is always felt at starting; therefore, the electric machine, having a great resistance to overcome, will turn slowly; the current will then be very strong, and the effort exercised sufficient to surmount the obstacle. The carriage once started, the resistance diminishes; the machine, and with it the vehicle, is accelerated; at the same time the current diminishes: and this continues till the carriage has assumed a uniform speed and the current has obtained the value necessary just to overcome the friction, which always tends to retard the motion.

If an ascent occurs, the carriage will go more slowly and the current increase again, so that the motor, in proportion to its slackened movement, will receive the increase of force necessary to mount the incline.

If, on the contrary, we come to a descending incline, it will itself accelerate its machine, and augment the counter-current in such a way as to diminish the propelling force. It may happen that the motor will turn as quickly as the generator, which will completely annul the current; and it may even be that the motor, being hurried along by

the vehicle, will turn faster than the other; then the direction of the current being reversed, the motor, instead of receiving work, will have to produce it, which will tend to slacken the speed of the carriage, and thus constitute an electric brake.

Dynamos may also be made powerful brakes by short-circuiting the machine fixed to the vehicle. The machine, being driven at great speed by the momentum of the vehicle, produces through the short circuit a very powerful current, which pulls the machine up, and thus puts a powerful brake on the wheels. This means must only be employed with great care, for the whole of the electricity thus generated is turned into heat in the machine and in the short circuit, and may, if too strong, burn up the machine and its connections. However, carefully applied, this means may be very useful; it may be of extreme importance in a moment of danger, where it may be necessary to stop the vehicle on the spot, whatever it may cost, and where it might be important to sacrifice the machine for the sake of the passengers.

The electricity was conveyed to the motor from the generating machine by a simpler arrangement than in the first case; it was led up by one of the rails, and the other formed the return. It was necessary for the rails to be insulated from the ground, which was managed by taking care that they only touched the sleepers on which they were fixed. The current was then brought up to the

machine through the tyre of one wheel, and returned by that of the other.

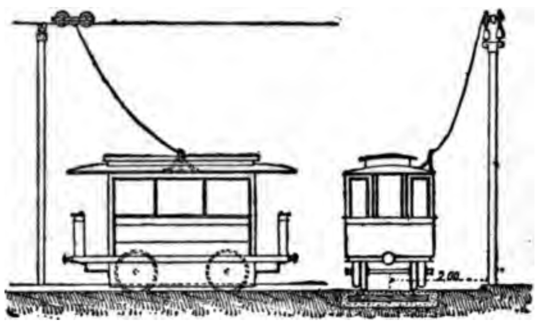
This simple and inexpensive arrangement developed grave faults in practice: in the first place, the insulation is very difficult to preserve, and, notwithstanding every care, great loss of current often arose; and, in the second place, where the rails are crossed by a road, it might happen that a man or a horse should touch both rails, which would then afford a derivation for the current, and might occasion a violent and dangerous shock. This system is retained in Lichterfelde, but for other applications it is proposed to give the current a special conductor.

For this is arranged along the route a line of posts supporting a wire, and on this wire runs a metal carriage drawn by the conveyance to which the current is furnished. This arrangement, shown in Fig. 99, has in fact been applied in several cases, especially to the tramway shown at the Exhibition of 1881, as to which we shall have something to say presently.

At Lichterfelde, for the first time, a difficulty inherent to this means of transmitting power was made evident; we refer to the continued variation in the resistance interposed between the two machines. At starting, the motor is quite close to the generator, but the further it goes the greater is the distance between the two, so that the power transmitted becomes weaker and weaker. In a very short run, this fault is not of importance, and in the Lichterfelde railway it was slight, owing to the large size of

the rails employed as conductors, and their slight electrical resistance, but it was perceptible. It became very marked with the overhead conductors which have just been mentioned, and which were necessarily restricted in size, and the resistance relatively great. We shall presently see that the way to overcome this difficulty is in an appropriate

FIG. 99.



employment of the electricity and the use of high-tension currents.

If the applications of electricity to railways by Siemens and Halske are by far the most numerous and important, they are not the only ones. We must mention the experiment of Edison in his laboratory at Menlo Park. There are however no particular adaptations to record in this case; they were very much the same arrangements as those of the Berlin experiment described in this chapter.

Similar trials have been made in France by Messrs. Chrétien and Félix, who use Gramme

machines; they were shown at the Electrical Exhibition, and we shall presently describe them.

Before, however, referring to this Exhibition, we must mention sundry other applications. Siemens and Halske put up a lift at Mannheim, and we mention it here to show the date, for we shall meet with a similar more complete and perfect application at the Exhibition; the arrangements at Paris being essentially the same, it will be more convenient to describe them.

At the sugar factory of Sermaize Messrs. Félix and Chrétien made use of electric transmission for several purposes, particularly for the discharging cranes. In factories of this description active work only takes place at one season of the year; during the other months of the year the central engine has almost nothing to do. Here there was an opportunity to make use of its power at other points than in the factory itself—for example, on the discharging quays. The apparatus is also very simple, as will be seen on reference to Fig. 100.

It is a crane formed of a long arm or rocking lever carrying a chain with brackets or trays. A Gramme machine is placed on the movable erection supporting this lever. The upper end of the lever is furnished with a counter weight, and attached by a rope or chain to the barrel, which is worked by the electric machine. The whole thing is brought alongside the vessel to be discharged; the barrel is started, and the lever is lowered till its lower end is in the boat. The lever is then made fast, and the

FIG. 100.

electric machine connected to the bucket-chain which brings up the beetroots to be landed, and empties them into the trucks arranged for their reception.

Several such apparatus are placed along the quay, and can be set in motion by the workman by the simple means of a switch.

A similar though more complete installation has been put up by Dr. (now Sir) William Siemens in his English farm. In this case a portable engine in the central building sets in motion a Siemens dynamo. The different points where work is to be carried out are connected with the central works by conducting-wires, some stationary, others movable and fixed at will. Dynamos are arranged where the work is required to be done, whether in the field, in the barns, or elsewhere: it is only necessary simply to connect the conducting wires with the machines. Thus, in every part of the farm, the current being produced in the central building by means of a steam engine may at any moment instantly be switched on for use. We may add that the electric current thus generated is employed at night for lighting purposes, and has been used for very interesting experiments as to the development of vegetation under the influence of electric light.

CHAPTER VII.

TRANSPORT OF FORCE AT THE ELECTRICAL EXHIBITION OF 1881.

THE Electrical Exhibition which took place at Paris in 1881, and which was so brilliant, contained numerous examples of the electric transport of mechanical work. We cannot say, however, that there was any very new revelation made on this point, except in the exhibits of Marcel Deprez, of which we will speak by themselves.

As to the rest, we find currents transmitted in a similar way to those of which we have been speaking: that is to say, worked at a short distance by means of machines of known patterns. Even from this point of view there was very little appearance of innovation; all the transports acted, with the above-named exception, by means of the two types of machines spoken of in the preceding chapters, the ordinary Gramme machine and that of Siemens. Among the numerous new forms of machines produced at this Exhibition, none were applied to this purpose. The study of the transport of force by electricity as shown at the Exhibition would be reduced to a very brief and dry enumeration, were it not for a few not uninteresting peculiarities of some of the exhibits.

To dispose of the least important first. Several firms exhibited whole work-rooms of sewing machines, all driven by electric motors. All were arranged in the same way; whether they were exhibited by the firms of La Ménagère, or Baclé, by Bariquand or by Hurtu and Hautin, all consisted of a certain number of sewing machines connected mechanically with a common driving-shaft; a dynamo set this shaft in motion, and the machines worked. In all the exhibits just mentioned, the Gramme machine was employed.

It was the same with the machinery of Donnay Huré, Mouchère; the instruments worked varied, planes, lathes, etc., being shown in motion, but were always driven by a Gramme machine, receiving the current from a similar one placed at some distance in the Palais de l'Industrie.

Among the exhibits of this sort, the first to be mentioned is that of Heilmann, Ducommun, and Steinlin of Mulhouse. They set up on one side a regular battery of Gramme machines driven by steam-engines, and on the other a practical engineer's workshop, worked by a shaft driven by the other Gramme machines receiving the current of the first. The distance of transport was of course, as in the above-mentioned cases, very short; not more than 100 metres.

We must also mention Geneste and Herscher's installation; here a single generating machine served to set in motion three receiving machines. It was a sort of vague attempt at distribution of electricity,

of course very incomplete, but nevertheless interesting, and to be noticed as having some originality.

We now come to the exhibits in which the electric transport of force was the special object of demonstration. We will speak first of that of Chrétien and Félix. They reproduced at the Exhibition the electric plough executed by them at Sermaize, of which we have already spoken: there is no need to say any more about it, as the whole machinery was exactly as we have already described it; to this was added a new apparatus constituting a sort of railway. Strictly speaking, it was a truck something like the tender of a locomotive engine, the wheels of which were connected by an endless chain to a Gramme machine inside the truck; the current, brought by one rail, returned by the other, as in the Lichterfelde tramway described above.

The firm of Chrétien and Félix also exhibited a number of tools: for instance, a timber saw-mill in which the saws were set in motion by a Gramme machine; a rotary pump whose axis was connected direct to that of an octagonal Gramme machine. Last, but not least, was an atmospheric rock-borer, for cutting and detaching blocks of stone in a quarry; for this purpose it had a sort of solid scissor-blade, which moved with a rapid alternating motion, striking the stone, where it is required to be cut, a succession of rapid blows. This operation is accomplished by means of compressed air to make the blow more elastic. The electric machine was used to

give the rapid alternating movement to the piston working the apparatus. There was also to be seen a hammer, striking very rapidly and worked directly by a Gramme machine. This exhibit, as we may see, was important for its extent and the number of objects exhibited, but it added nothing on the whole to what had already been seen in France. The distance of transport was not more than the width of the Palais de l'Industrie.

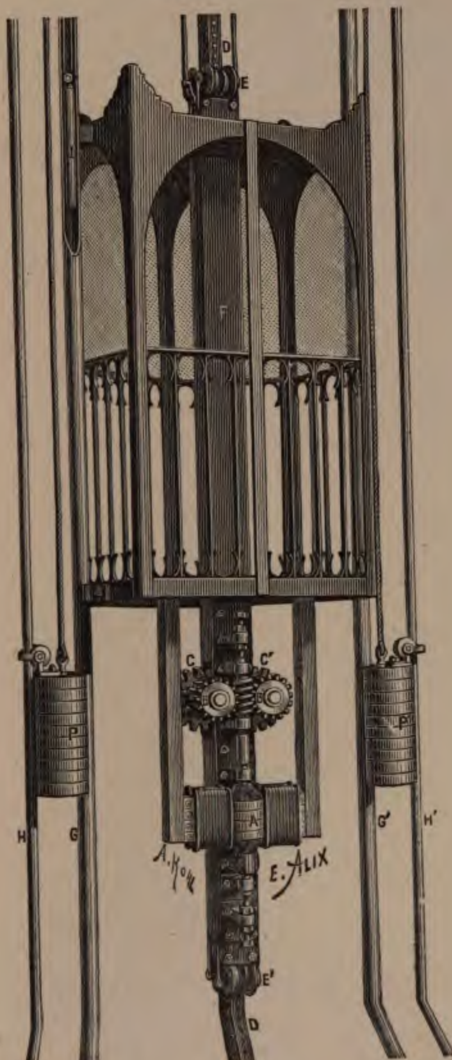
Messrs. Siemens and Halske's exhibition was more original—indeed we ought to say exhibitions, for this noted firm exhibited in the German section as a firm, in the French section by right of their branch in Paris; in the English section in the name of Dr. (now Sir) William Siemens, brother to Dr. Werner Siemens, head of the German firm. A fairly interesting installation of a collection of tools was made by them in the French section; among them were much the same as the others—lathes, planes, rotary pumps, and besides an electro-plating bath. On this point an important remark must be made. We have already said that, to transmit force most economically and conveniently, electricity of high tension must be employed in order to use a smaller quantity; the contrary is the case for electro-plating. Experience shows that to obtain a metal deposit, the lower the pressure of the electricity the better. It follows from this, that the electricity used to transmit force is not fitted to deposit copper or gold. This defect is obviated by an ingenious contrivance: the electricity produced by the central engine is employed not to

deposit the metal, but to turn a motor, which in its turn sets in motion by means of a belt another dynamo; it is this last which furnishes the electricity for the galvanic bath, and it is so arranged that the electricity coming from this is suitable for the purpose. It is true that by these various transformations of electricity into force, and force into electricity, a considerable loss is sustained; but the object is attained, which could not be the case if the electricity employed for the transport of force were applied direct.

The Siemens firm also exhibited two very interesting applications: the first, which was not completed till nearly the end of the Exhibition, was a lift represented in Fig. 101. The apparatus consisted of a toothed upright, or more precisely a narrow ladder with the rungs very close together; two cog-wheels C, C^1 fitted their teeth in between these bars. These wheels by means of an endless screw were connected with a dynamo-electric machine A. When the latter received the current it began to rotate, setting the wheels in motion, and these fitting into the ladder caused the whole contrivance to ascend. A platform was fixed to this arrangement and moved with it, thus carrying the persons on it up or down. The necessary current was furnished by an engine at a distance of several hundred metres in the Palais. A lift of the same sort had been exhibited the previous year at the Mannheim Exhibition.

This application of electricity was curious and interesting, but on a closer inspection it might have

Fig. 101.



been much criticised, especially as regards the mechanism, which absorbed much force.

A less novel, but in many respects more interesting application, was the electric tramway installed by the Siemens firm and run between the Palais de l'Industrie and the Place de la Concorde. The general arrangement was very like that of the railway at Lichterfelde; the vehicle was much the same, as may be seen from the accompanying Fig. 102, but differed in certain important details. It will be remembered that at Lichterfelde the current was brought by one rail and returned by the other; for this the rails were slightly raised from the ground, being sustained and electrically insulated by blocks of wood. A similar arrangement was at first intended to be employed in Paris, the railway being raised to a certain height on a framework of wood and iron. The permission to carry this out arrived, they say, too late. It may be doubted whether it was ever given, the nature of the place being such that a tramway of this nature would have greatly interfered with the traffic, even ordinary raised rails not being permitted. They were therefore obliged to use grooved rails like the ordinary tramways of Paris, that no projection should disturb the level of the road. The conditions were thus completely altered, and there could no longer be any question of communicating the current by means of the rails, these not being capable of insulation. It was resolved to provide a special conductor for the current, which could then descend through the wheels and return by the rails and the earth.

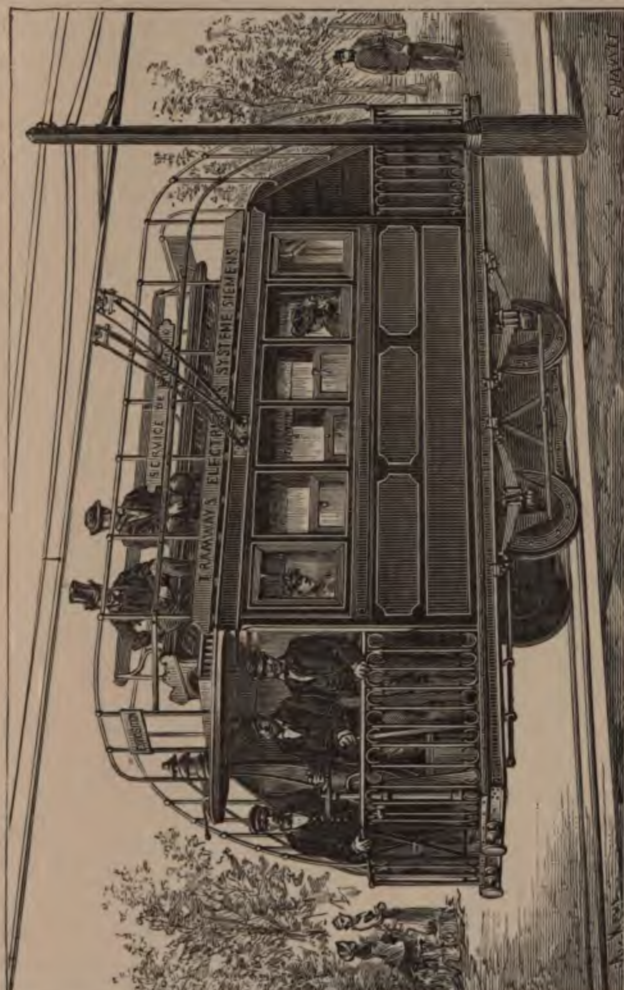
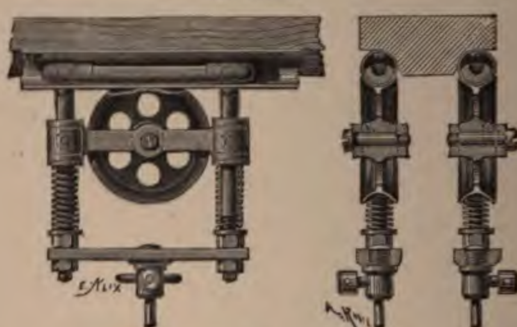


Fig. 102.

In trying this, a new difficulty presented itself: the rails being on a level with the ground were covered with mud and dust; and it will be understood that this would suffice to impede communication between the wheels and the rails in such a way that the return was very badly effected. It was therefore decided to erect a conductor to transmit the current both ways.

After much thought and repeated experiments, these conductors were formed of two copper tubes

FIG. 103.



slit lengthways and laid along a small piece of wood suspended horizontally to posts erected along the road. The movable rubber or jockey, to connect the rubber with these tubes, required very delicate adjustment; the form given in Fig. 103 was finally adopted. The contact was made, as will be seen, by a metal cylinder placed in the tube, one end of which was connected to the other across the longitudinal slit; a roller wheel worked on the tube and

was pressed against it by springs, so that the contact took place both at the piece sliding in the tube and by the wheel rolling on the outside; this was amply sufficient. Each of the two conductors had a runner of this description, which was attached to the tram by insulated conducting wires; the current was brought by one and returned by the other.

This plan worked very well during the time of the Exhibition. The vehicle would have gone at the rate of 70 kilometres an hour, but it never exceeded 20 kilometres, in consequence of the short length of the course and the sharpness of the curves. It has, however, proved to all the practicability of electric railways.

Besides these exhibits must be mentioned those of Gravier de Varsovie and Marcel Deprez; but these will be treated further on, as in them the question of electric transport of force is much complicated with a still more comprehensive and important subject, that of distribution of force. These two exhibitions gave two solutions of this question, of very unequal value, it is true; that of Gravier being quite elementary, while that of Marcel Deprez is of great importance. We shall speak more particularly of these further on.

CHAPTER VIII.

RECENT APPLICATIONS AND EXPERIMENTS.

ALTHOUGH the Electric Exhibition, with the above exception, did not show any marked progress on what had already been done in the way of electric transport of force, yet it exerted the same good influence as the others—it made publicly known the results obtained, and published the proceedings. Since its close several interesting applications of the transmission of power have been made. At La Rochelle two octagonal Gramme machines were used to bring into the town part of the force of a waterfall situated at a distance of about 3 kilometres. The motor worked a rotary pump which furnished water to part of the town: this installation is in every way similar to those mentioned in the preceding chapter about the Exhibition, but it is no longer only a demonstration but a practical application, which is sometimes very different. This system, which has been in use for more than a year, still works well.

At the cannon foundry at Bourges is now being installed a curious transport of force; it works a travelling crane. This apparatus, as is known, moves on rails, and should be able to act at any part of its

course; it generally has a steam-engine joined to and moving with it. At Burges a very powerful crane was wanted, capable of developing about 12 horse-power. An engine of this power is very heavy, and it was very difficult and troublesome, if not impossible, to join it to the crane; besides, there was power to spare in a workshop about 200 or 300 metres from where the crane was wanted. Electricity solved the question, the officers have promptly taken it up, and the apparatus will shortly be completed. According to the scheme, the current brought by a special conductor will return by the rails. The machines are of the Gramme type, set up by Chrétien and Félix.

Along with these examples we will mention one which is very peculiar. At the bleaching establishment at Breuil-en-Auge, near Lisieux, owned by Duchesne-Fournet, electricity is employed to gather up the linen. For bleaching and drying purposes the pieces of linen are spread out in the fields, and this has to be repeated many times.

Dupuy, engineer to this firm, laid down along the top of the meadow a small railway. The train running on this consists first of two trucks, of which the foremost contains Faure accumulators. We have not yet had occasion to speak of these accumulators, which have lately been much talked about; we will only say that the Faure system is a modification of an important invention, due to Graston Planté; it was the latter who invented an apparatus in which electricity may be stored up and used whenever required. The truck carrying the accumulators is therefore the

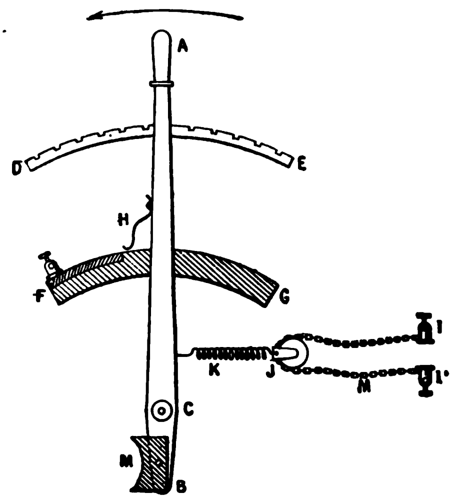
source of the electricity. Behind this is the second truck containing the motor, which we represent in

Fig. 104.

Fig. 104. A Gramme machine is employed. It is connected on one side with the wheels of the truck,

on the other with a folder. Behind this truck are arranged others carrying baskets to receive the linen. This is collected in the following manner: The current from the accumulators is sent into the machine and the train begins to move; on arrival at the first piece of linen, a lever, shown in Fig. 105, is worked, which has a double mission, namely, to disconnect the

Fig. 105.



current and put a brake on the wheels. The end of the piece of linen is then taken by the folder; this is connected with the motor and the current is switched on, thus starting the folder which takes hold of the long piece of linen, raising it to the baskets in the trucks behind. When one piece is gathered up

the motor is reconnected with the wheels, and the contrivance moves to the next piece.

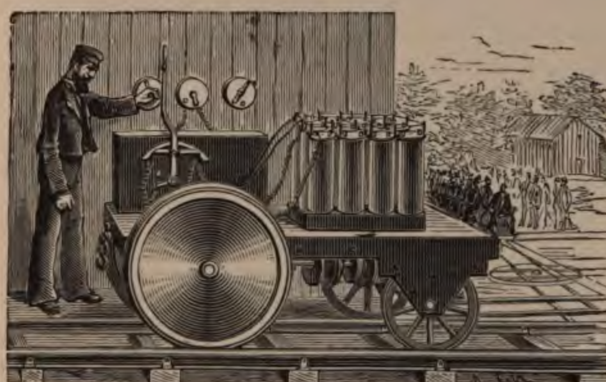
This arrangement is evidently only moderately advantageous; the accumulators are very heavy, about 800 kilogrammes being required, which make a considerable dead weight. In working it in this way the principal advantage of electricity is lost, which is to bring force from a distance, as we have said; in the arrangement of which we are speaking, it is only the aptitude of the electric agent to produce work that is turned to account, not its facility of transmission; but in this case the arrangement adopted was ruled by various circumstances.

In the first place, electricity was necessary. The steam engines were obliged to be far away from the meadows, as their smoke was disastrous to the linen; on the other hand, the meadows are very damp, and and it was impossible to insulate the rails so as to serve as conductors for the current; it would therefore have been necessary to set up a special conductor, as for the tramway at the Exhibition. The accumulators were preferred, as being less expensive, and as the train never had to go quickly, the weight was no great inconvenience. A new application of the same thing has just been made in a bleaching establishment at Berlin.

In Fig. 106 is represented an electric locomotive, said to have been constructed by Murchisson, in which the motive force is produced by a simple alternating electromotor, acted upon by a Planté accumulator, which in the sketch is in the act of

being charged at the place of departure. De Graffigny, in his book entitled 'Les Moteurs Anciens et Modernes,' speaks of it as superior to that of Siemens tried at the Berlin Exhibition; but we cannot agree at all with this opinion, nor with that he expresses about accumulators, the principle of which he evidently does not understand. According to this writer the speed of the locomotive may be

Fig. 106.



modified by varying the intensity of the current, and might even be stopped almost simultaneously by applying the current to the wheels which should be made capable of magnetisation, and thus by their strong attraction to the rails their speed would be slackened. Further, the trucks were even to be held together in this system by magnetised buffers, which would allow of instantaneous separation; the

surplus power of the generator might be used to light an electric lamp at midnight to illuminate the road. These very complicated and useless arrangements are altogether improbable, and require serious proof; no use has ever been made of them, which compels us to leave them altogether out of the question.

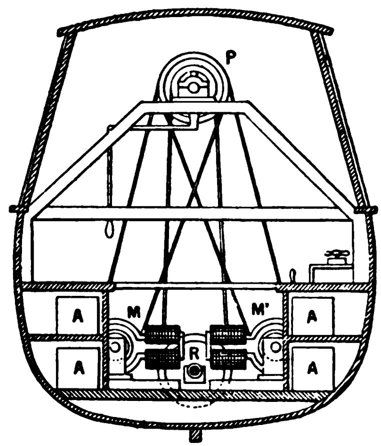
Lately, induction machines have also been applied to navigation, and the October papers of 1882 were full of experiments made on September 8th on the Thames, by means of a boat constructed by the Electrical Power Storage Company, and worked by Siemens machines. This boat, called the *Electricity*, was 7·62 metres in length, 1·52 metre wide, drawing ·52 metre forward and ·75 metre aft; it was therefore nearly as large as that of Jacobi. We give a section of it in Fig. 107.

The motor, composed of two machines, M, M^1, D^3 type, was placed under shelter nearly amidships. The belts of the two machines worked on the same pulley P, which set in motion another pulley R, placed on the screw-shaft. This last made 350 revolutions per minute, and the machines 950.

The current was supplied to the motors by forty-five Sellon-Volkmar accumulators, A A, with forty plates weighing 816 kilogrammes, and with an E.M.F. of 96 volts. It was said that this electric generator could furnish a current of 30 ampères, which would give four horse-power for six hours. The apparatus was completed by a commutator by which the number of accumulators might be varied.

There was besides a mechanical arrangement made by which either of the motors could be shut off at will; these were also made so that the machines could be reversed. There was thus every facility for stopping the boat quickly, and for going astern. The person in the cabin who attended to the commutator also steered. The whistle found in ordinary

Fig. 107.



steamboats was replaced by a large bell also worked by the accumulators.

The *Electricity* would carry twelve persons, but in the experiments made on the Thames between London Bridge and Millwall, only four went in her. The mean speed they went at was nine miles an hour against the current, according to information furnished by the experimenters.

Several smaller installations may be mentioned; we will first refer to that of La Belle Jardinière. In this large outfitting establishment there is on the top storey a workroom full of sewing-machines; it was wished to work these machines by means of a motor, but the engines being in the basement, the mechanical transmission was very difficult. The problem was solved by electricity: a Gramme machine below, another above, two conductors, and the transmission was effected. The women were thus saved the working of the sewing-machines, which is arduous and often seriously injurious to the health if prolonged.

There are also applications of this sort in the Grands Magasins du Louvre; one of which at least was started perhaps even earlier than that of La Belle Jardinière; it is used for the transport of force between the Magasins and a workshop in the Rue de Valois; the wire crosses the Rue St. Honoré, and the current sets in motion a collection of cutting-out and sewing-machines. The same method is employed in the workrooms in the Avenue Rapp; a number of sewing-machines are electrically driven by an engine situated at some distance from them.

A very interesting application has just been effected in the goods station of the Chemin de fer du Nord. In speaking of the Electric Exhibition we did not mention a small electric windlass exhibited in the English section. It was very simple: a Siemens machine, according to the direction of the current transmitted to it, wound or unwound an endless

chain, and packages could thus be raised or lowered. The apparatus set up in the Gare du Nord by the French branch of the Siemens firm is similar, only it is also provided with the means of moving from place to place, thus constituting really a travelling crane. To the beams of the goods station grooved iron rails are attached and suspended. On these rails works a sort of truck, containing a Siemens machine connected with a windlass. Above this arrangement run copper tubes as conductors; they are exactly similar to those described in speaking of the Exhibition tramway enclosing sliding contacts. By means of a chain, the current is sent into the machine, and this is connected, sometimes with the windlass which is then used to raise burdens, sometimes with the wheels of the truck which then carry it along from the loading to the unloading place, and *vice versâ*. The electricity is supplied by two Gramme machines about 350 metres away, and the working of this plan is completely satisfactory. We may expect shortly to see many similar applications.

Besides the foregoing, numerous important projects have been worked out and proposed; we cannot yet say how they will turn out, but it will be interesting to say a few words about them. We have already mentioned the projected tramway at Berlin; its arrangements are very similar to those which have been worked out by Messrs. Chrétien and Félix for a tramway to be erected on the Boulevards in Paris, between the Madeleine and the

Bastille. We will give a few details of this last project, which is very complete.

The double line of rails runs on a viaduct built the whole length of the way, which consists of an iron structure resting on a single row of large pillars; the space occupied is reduced as much as possible, and the height is from 5 to 7 metres above

Fig. 108.

the level of the ground; there are no crossings nor changes of line. The stations, branch lines, etc., are designed with great care and thought, and the general appearance is shown in Fig. 108. The motive power is furnished by fixed steam engines, specially designed, working Gramme dynamos by which the

electricity is furnished. This is conducted along the route by copper wires. Each tram carries a machine which receives the electricity, transforming it into power in a similar manner to those already described. The authors of the project proposed to have two generating centres for the length of the line between the Madeleine and the Bastille. The carriages, similar to the tramcars we have already represented, were to be 8 metres in length and contain fifty passengers; they would not be made up into trains, but each carriage would run singly and frequently like omnibuses. As we may see, all the details of the project have been well thought out, and the question of finance has not been neglected; an application was even made for a concession, but it is very doubtful if this project will ever be executed, at least in Paris, for the general opinion there seems to be in favour of an underground railway. It is, however, well to take note of this proposal, for similar tramways will certainly be built some day.

The recent Electric Exhibition at Munich has shown that this is still one of the questions of the day: some very interesting experiments were made there. Some confined themselves to arrangements already known, and developed no new peculiarities. Thus Edison set up a sort of dairy where the implements were connected to a driving-shaft worked by an Edison machine, which received the current from a similar machine at a distance, which however was in this case not more than a few metres. Schuckert exhibited some agricultural implements running

light, worked by an electric machine, but in this case the generator was situated at a distance of 5 kilometres, and was set in motion by the Falls of Hirschau. The distance of transport was therefore considerable, though not exceeding the limit of that already attained. We should say that the conducting wires connecting the two machines were of copper, 4·5 millimetres in diameter. This fact should be remembered, for it is not the distance between the machines where the difficulty is found; this, as we have said, lies in the resistance encountered by the electricity in the conducting wire, through which it must pass from one station to the other. This resistance increases with the length of the wire, which is the reason of the increased distance being an obstacle, but it diminishes when the wire is increased in size; it is also less when the metal of the wire is better adapted to the passage of the current, and possesses what is called a higher conductivity. Now everyone knows that copper is a better conductor than iron, and it is the latter which is used for telegraph wires; if we compare the conductivity of the two metals we find that in Schuckert's experiment the copper conductor of 5 kilometres was equivalent to 770 metres of telegraph wire: that is to say, if he had employed iron wire, it would have been necessary to place the machines only 770 metres apart in order to get the same effective return. This consideration is very important, for it is the difficulty of laying down the conductor which is the great trouble in the transmission of power. If it were

possible to place between two stations, however remote, a thick rod of pure copper, there would be little or no difficulty in the electricity passing, and the distance would be of no account; but this sort of installation would be an immense expense, out of all proportion to the useful results arising from such a transport. It is this question of expense which is definitely conclusive. When we propose to transmit force by electricity it is in order to turn it to good account, and this becomes impracticable if the installation is too costly. In these installations it is the conducting wire between the two stations that is the great expense, and it is therefore of primary importance to have this as thin as possible and of the least costly metal.

From this point of view, as also from others to which we will refer, the experiments made by Marcel Deprez at Munich are of the highest importance. He transmitted a force of about a half cheval-vapeur from the little town of Miesbach to Munich, 57 kilometres distant, making use for this purpose of the ordinary iron telegraph wires 4·5 millimetres in diameter. These wires were besides set up and insulated in the same way as for ordinary telegraph purposes, without taking any special precautions. This trial arose from what had already been done, and which we have described above: this marks a very important step, and we will explain it more particularly.

In electric transmission of work nothing is created any more than in any other case; we only apply

work performed by some special action: therefore we can reap no more force in any particular instance than is generated by that action. This quantity is defined, and is capable of being measured: this is in fact what we can do for electric currents. If, as we have already said, we take E to represent the electromotive force which propels the current, and call the intensity I, the total force generated by this current will be represented by the product E I. We wish to turn it into mechanical work, the value of which we represent by T; if our transformation were perfect we ought to obtain the whole of the force of the current in work, when we could make $E\,I = T$.

Unhappily, this equation cannot be realised. There is, besides, an element of which we have taken no account. To have an electric current we must have a conductor to convey it, and this more especially when transmission is required, for it serves to conduct it to a distance; and we know that any conducting body offers resistance to electricity.

It is precisely this resistance to the flow of electricity which we have ignored, but we know that this resistance always manifests itself by generating a certain amount of heat in the passage of the current. We learn how to measure this heat by a law discovered by Joule. If we take R as the resistance the electricity has to overcome, and I, as we said above, for the intensity of the current, the total heat generated is expressed by the product $R\,I^2$ (I^2 being of course the square of I, or I multiplied by itself).

This heat is produced at the expense of the force generated by the current, and our equation, to be correct, must stand thus: $E I = R I^2 + T$.

We see at once that the quantity $R I^2$ is to the detriment of T; it means a loss, and as we cannot entirely suppress it, we must endeavour to reduce it to the smallest possible dimensions. The first means is to reduce R. Looking at the whole question, we see that R is composed of three parts; the first, which strikes us immediately, is the conductor which unites the generating station with the receiving machine. We have just referred to the difficulty found in reducing the resistance of this conductor, which becomes a question of expense and necessitates the consideration of economic requirements. The two other parts of R are not so striking at first, but will be found in the machines themselves. We must not forget that they are formed of wire coils, which the current has to traverse, and where it also meets with resistance; other things being equal, it is of value to reduce this as much as possible.

After diminishing R, we have yet another means of reducing $R I^2$; it is to lessen I. We may do this, no doubt, but on one condition: admitting that it is advantageous to reduce $R I^2$, which is the loss, we must not reduce the product $E I$, which is the energy at our disposal; we can then only reduce I by increasing E, so that $E I$ may not be less. From which we see that to obtain an economical transmission we are obliged to employ currents of low intensity but high tension.

We may even go further: we have already seen (Chapter V.) how the machines act in the transmission of force. A generating machine turning at a certain speed sends its current to another machine, which we will suppose similar to the first. The second starts, and if doing no work, goes at the same speed as the first; in this case, as we have seen, the current generated in the circuit is nil. Why? The explanation is simple. The second machine in revolving generates electricity, as does the other, and tends to produce a current in the opposite direction to that of the first machine, and neutralises it to a certain extent. If the two machines are going at equal speeds, the currents are equal; they cancel one another entirely, and no current is apparent in the circuit. If, however, one of the machines goes slower than the other, the contrary currents are unequal; there is a difference, which is shown in the form of a current of more or less intensity. That is what happens when the second machine is at work; it is retarded by this work, and the current shows itself with an intensity great in proportion to the reduction of the speed.

We may then consider the receiving machine as an electric generator working in the same circuit as the other, but in the opposite direction; it is then, like the generator, the seat of an electromotive force, and as we have called the first E, we will call the second e. In the system of two machines which we will consider, there is only one current flowing through the two; there is then only one intensity,

which we have called I. We have seen above that the total energy produced by the generator was EI, so experiment and theory show that the energy developed by the receiver is shown by the formula eI; it is the total work which it can develop, and is the value of the quantity we have hitherto called T, and our equation therefore takes the complete form, $EI = RI^2 + eI$.

It is very important to know what is the proportion of the work obtained, viz. the ratio between the energy recovered and the whole energy expended. This is the return, and we may ascertain it without difficulty *electrically;* the real *mechanical* return is of course less, owing to friction, etc. The work generated is EI, the work recovered is eI, and the return will then be $\frac{eI}{EI}$; or cancelling I common to the two terms of the fraction, when the circuit does not present excessive loss, the return is equal to $\frac{e}{E}$. It will be seen that the resistance is not taken into account in this formula, and as the resistance represents the distance of the transmission, we are led to conclude that the return does not depend upon the distance. It must be observed that if the amount of work recovered and the loss suffered are fixed, that is to say, the return, the figures may be, as we have said, chosen without reference to the distance; but this can only be the case if the electromotive forces fulfil certain precise conditions, and reach certain ascertained values.

These laws were guessed at in the years preceding the Exhibition, and, as we have said, a tendency had been shown to employ electricity of high tension for the transmission of power, but this progress was more instinctive than reasoning. It is to M. Marcel Deprez that we owe the entire theory as we have given it; he was the first to show, in the years 1880–81, that it was possible to obtain at any distance any required force with a return fixed beforehand, provided only that certain requisite electromotive forces were given to the machines.

He did more: he showed how to obtain these electromotive forces with certainty.

Till then dynamo machines had been treated in a somewhat empirical manner; certain laws which governed them were well known, viz. the laws of electric induction formulated by Ampère and Faraday, but certain points remained in an obscurity which is not even yet entirely dissipated. Among these little-known points, the magnetisation of iron by electric currents must be placed at the head. The machines, as we have shown, produced electricity by rapidly passing wires before the poles of an electro-magnet; this forms part of the machine itself, and its variation depends upon that of the machine, and unfortunately the laws of this variation are unknown; every time a machine was modified or a new one was made, there remained perforce an unknown element which influenced the result. By a very happy conception M. Marcel Deprez showed that the machines might be varied

without modifying this mysterious magnetic field, and that the known laws were sufficient without taking the rebellious element into account, which remained invariable. From that time it became possible to determine beforehand the results that would be obtained from any machine, and to construct it with a degree of certainty till then impossible.

After very complete laboratory studies in this sense, the principles which he enunciated were very minutely verified, and he obtained the remarkable result of which we have spoken, and which was the first example of the electric transmission of force to a great distance under practical conditions.

Since the Exhibition much has been done in the way of experimenting, and M. Marcel Deprez has recently surpassed himself in his experiments at the Chemin de fer du Nord in Paris, where, with two machines specially constructed by him, he succeeded in transmitting two horse-power through an ordinary telegraph wire 4 millimetres in diameter, nearly 10 miles long, this being done with an expenditure in the motor of about 6 horse-power. At another similar experiment about 10 horse-power was put into the generator, and about 3½ horse-power received at the motor. In these experiments, however, the machines were placed side by side, two of the poles being joined by the long wire and the other two poles by a short thick wire. To this arrangement some objection may be taken on the ground that it would not correspond with actual conditions of

working, supposing the machines to be 5 miles apart and joined by two telegraph wires, and these experiments have, in consequence, been very much criticised. In the notes at the end of this work will be found a translation of the report of M. Tresca, presented to the "Académie des Sciences" with all the electrical and mechanical data of the various experiments.

Many important projects are now also in hand for the practical application on a large scale of the transmission of power by electricity, chiefly for the purposes of locomotion. Among these we may mention the subterranean railway at the mines of Zankerode in Saxony, the Portrush railway in Ireland, the proposed railways in Switzerland and in Cornwall, both of which are to be worked by the natural forces abounding in the districts; also the underground railway from Charing Cross to Waterloo Stations, which is to run underneath the Thames through a tunnel, and the whole of the traffic is to be worked by electricity, Messrs. Siemens Brothers being the contractors. The necessary Bill is now before Parliament, and without doubt the works will very shortly be begun.

The two first-mentioned railways, those at Zankerode and Portrush, have actually been accomplished, and merit description. In the former case, as the railway was subject to rough usage in the mines, and the rails could be but imperfectly insulated, recourse was had to another method of supplying the locomotive with the current. Two T iron rails

inverted are fixed to the roof running the whole length of the line, and on these work two carriages connected by insulated flexible conductors to the terminals of the motor, which is fixed with its axis lengthwise on the car and works one pair of driving-wheels by means of bevel gearing. The engine is reversible, and the starting or stopping gear, etc., can be worked from either end. The weight of the locomotive is about a ton and a half, and it can develop power sufficient to draw a load of 8 tons at the rate of 7 or 8 miles an hour. The work was designed and carried out by Messrs. Siemens and Halske.

The Portrush railway is another example of the successful application of electricity to locomotion. This line is single and is six miles long, uniting the towns of Portrush and Bushmills. The power is at present supplied by a steam-engine, but it is intended to replace this by water power obtained from the Falls of the River Bush in the neighbourhood. The iron conductor consists of a well-insulated iron T rail running alongside the line, two steel rubbing springs making contact to the dynamo, after passing which the current goes to the wheels and thence by the uninsulated rails to the generator. The line is in reality a tram-line, and parts of it run through the towns and the remainder alongside the existing road. There are, therefore, several places where the T iron conducting the current has to be broken; in some the opening is not equal to the length of the car, therefore the two brushes are used so that

contact is made with the next conductor before it is broken on the one before, but in other cases, where the openings are wider, the car has to run by its own impetus over the break. This is easily managed in practice. Where the breaks occur the current is conveyed by copper conductors well insulated and buried underground. Comparisons have been made as to the expense of working the line by electricity and by ordinary steam tram locomotives, and from practical experience the electric method is shown to be extremely favourable, even when steam power is used to generate the current; but when the water power can be made use of the economy will be very marked, and the wear and tear of the permanent way will be very much less than with steam locomotives, owing to the very much lighter rolling stock required.

We must here notice a proposal of Professors Ayrton and Perry for the supply of current to a train in motion. The earliest experiments in electric railways showed the difficulty of supplying the current through the rails, owing to the impossibility of obtaining perfect insulation thereof. For a short distance this could be managed, but on a long line the leakage became too great for this plan to be economically used; these inventors therefore propose that a long line should be divided into small sections, each moderately but not perfectly insulated. The current would be supplied to each section by means of well-insulated copper conductors running along the line, and each train as it arrived at a section

would automatically close the circuit by acting on a lever; as long as it was on that section it would be be supplied with current, and as it left it, it would shut off the current from the one it had just left, and turn it on to the new one. By this means the rails might be used to convey the current to the motor, and at the same time very efficient insulation obtained. This would also provide a very perfect system of blocking, for it might easily be arranged that no current could be supplied to a section immediately behind one on which a train was at the time, so that a train behind, on coming to that section, would stop of its own accord until the train in front was out of danger. This invention has not yet been applied, but it appears a very good arrangement.

We have already said that the electrical transmission of energy will no doubt be first applied in the utilisation of natural forces, hitherto useless on account of their situation, and at the head of these are waterfalls. It may be that at first sight one is not struck with the importance of these forces, but let the reader reflect a moment, and he will be able to call to mind some forces in his neighbourhood which have hitherto remained unemployed. Rivers have nearly always falls which might be utilised; for example, the weirs in the Seine, in the vicinity of Paris, might be made to yield 2000 horse-power each, and there are three within a radius of 10 kilometres. There are few places near which there are not numberless instances of enormous natural

powers at present wasted: for instance, the numerous falls of the Thames, near London, and the vast power of the tide in the lower parts of the river would suffice, not only to light up the whole of London, but also to supply it with all the motive power required; and it is not necessary to mention the often quoted Falls of Niagara to show that there are around us innumerable sources of energy, the sum of which would add immensely to human power.

This is only one instance of the transport of force, which is the most striking and will undoubtedly be the first utilised, but there are others: the enormous power of the tides may be utilised; the irregular, but at the same time very great power of the winds may be accumulated and transported, and there are many others. From a general point of view it is a valuable property, that we are able to give to power a sort of privilege of ubiquity; its advantages are thus multiplied in an immense proportion, more especially if to it may be joined the property of sub-division, of which we will now treat.

CHAPTER IX.

THE DISTRIBUTION OF ELECTRICITY.

It will have been seen from the preceding chapter how useful it is to be able to transport a power, and how this property has already received and will yet receive numerous applications. The question appears most promising, for in this way we shall be able to bring to the work to be executed the very great natural powers, such as those of waterfalls, hitherto useless. But the problem is not thus completely solved. Suppose in fact—and the case will certainly happen—that a force of 1000 horse-power has been reclaimed and transported; advantage must be taken of it. But there are comparatively few establishments which have need of such an amount of motive power, and it must be divided among several factories; this is possible, within certain limits, by mechanical means, but the distance is very restricted, and it can only be done at great expense and with great loss of power. The true solution is evidently to divide the electricity itself, and only to transform it into mechanical energy after it has been distributed among the consumers. The distribution may in t' manner be more easily managed, electricity b

easily divided and distributed by means of simple conducting wires. A much larger subdivision may therefore at once be imagined, almost unlimited: not only will a greater power be distributed among several manufactories, but in each one the motive power will be again sub-divided to supply each individual machine or tool; further, the total current will be sub-divided into numberless separate currents, each supplying separate places, whether factories, works, or private houses, thus distributing everywhere the numerous advantages of electricity.

All that is, no doubt, possible, but on the condition that this subdivision of the current is carried out with regularity and certainty. It is necessary that every individual apparatus and consumer shall receive the allotted portion without influencing the others; in a word, electricity must be distributed in the same way as water.

The problem is not without difficulties, for although it is easy to subdivide electricity by simply presenting to it an open passage, it is not so easy to do so in a precise manner.

First let us recall Ohm's fundamental law. We know that if we call I the intensity of the current, E the electromotive force of the generator, and R the resistance of the circuit, the proportion between these two quantities is expressed by the equation $I = \frac{E}{R}$. Suppose then that we dispose of a source of elec- ·icity and distribute the current equally among ·eral machines (which may be lamps, depositing

baths, motors, etc.), which for simplification we will suppose all similar. We connect the first apparatus, and a certain order of things is the result; a current of intensity I resulting from the electromotive source E and the resistance R is established, and the installation is adjusted: we have now to put on a second apparatus; how is this to be done? We will first put it following the other, and on the same circuit, but then its resistance will be added to that already existing and the intensity cannot be the same—it will be diminished; consequently, if the installation was before properly adjusted, such can no longer be the case, and both the first and second machines will be insufficiently supplied. To re-establish the previous state of things and maintain the original intensity of current, we must, in proportion as we introduce in the circuit any apparatus increasing the resistance, increase the electromotive force of the generator, i. e. give it a suitable regulation.

Before adopting this means, let us try another way. In the first case, having one machine in the circuit, we put the second in the same circuit; instead of doing this, we might make another circuit for the second apparatus, thus affording the current another path. Let us see the result: with the first apparatus the current had an intensity, $I = \frac{E}{R}$, and everything went well; we introduce a second apparatus on a second circuit, the current thus finds two paths open instead of one, the resistance is therefore half as great as at first; R is diminished by half, and

becomes equal to $\frac{R}{2}$; it follows, then, that the intensity I will be doubled; thus doubled it will divide itself between the two similar paths open to it; the first apparatus will maintain its intensity I, and the new one will receive another similar intensity. From this it would seem that the problem was solved; but unfortunately the reasoning that we have given is not exact, and we have neglected a necessary element. We have admitted that in offering to the current two circuits instead of one, the resistance which it would have to overcome would be halved, which is not correct; in fact, the resistance through which the current has to flow does not consist solely of the two circuits on which are the machines, it includes also the individual resistance of the generator. Whether this be a machine, a battery, or whatever we may suppose, the current must always traverse it, and it always meets with a resistance therein; it follows therefrom that by doubling the exterior circuit presented to the current we have halved the exterior resistance, but we have not touched the resistance of the generator, which is called the interior resistance. The total resistance has therefore been diminished, but not by half; therefore, although the intensity has been increased, it has not been doubled, as we supposed just now, and our installation is still defective: it could only be exact by doing away with the resistance of the generator, which is impossible. In default of this means, we must vary the electro-

motive force of the generator, or in other words, effect a regulation.

In whatever way we may work, we are therefore obliged to regulate the electric generator according to the demand of energy caused by introducing other apparatus successively into its circuit.

In looking a little more closely into the question, we see that to be satisfactory this regulation must comply with three conditions :—

1st. The several apparatus placed under distribution must be separately supplied; that is to say, each must receive its necessary share of electricity at any moment and in any place, without affecting the others placed in the same circuit.

2nd. The generator must therefore continuously furnish all the force required, but not more, or there will be loss.

3rd. The movement of electricity being very rapid, it is of importance that the regulation necessary to fulfil these conditions should be automatic.

Such are the necessary exterior conditions for any distribution to be complete.

Before enumerating the attempts made in this direction, we will glance at the conditions which they ought to fulfil.

As we have said, there are two ways of supplying several electric apparatus from the same source. The first consists in putting them one after the other in the same circuit, or in series; the second is when each has a separate circuit, or rather a separate

branch off the main circuit. This arrangement is variously called in parallel, in multiple arc, or in derivation.

In both cases, if it is required that the various machines should receive their proper supply of current continuously, and that the addition of one should not affect the others, a regulation of the electromotive force or the current must be effected, the nature of such regulation depending on the system adopted, whether the series or parallel.

For example, suppose we wish to utilise a waterfall which, we will say, is of great height but of small volume, and we arrange a set of water-wheels one under the other, so that each receives the whole of the water escaping from the one above it. Each wheel then utilises the whole of the volume of the fall, but only a portion of the head. If with this arrangement we wish to add another wheel, we must put it above the others, and consequently the height and not the volume of the fall must be altered.

If, on the other hand, we have a broad fall but of moderate height, we may take off a certain number of channels of suitable width, and in each place a wheel. Then each wheel will utilise the whole of the height of the fall, but only a portion of the volume. If we want to add another, we must take off another channel for the current, when the total volume of water must be increased, the height of the fall remaining unchanged.

The two above-mentioned arrangements for electric

machines are somewhat similar; if they are placed one after the other in the same circuit, when one is added we have only to increase the tension which corresponds to the height of the waterfall without increasing the amount of the current. If, however, they are in parallel, and the number is altered, the current must be modified, the tension remaining the same.

We have thus two modes of regulation. The series arrangement has many defects, for in the first place each machine is dependent on all the rest. If one of them meets with an accident, all the others are at once stopped; and further, very great variation in the electromotive force is pre-supposed, and extremely high tensions would often be necessary. This arrangement is theoretically possible, but it is doubtful if it could be practically employed. The parallel system appears more possible and certain in its action, and is the only one which has been at all used hitherto.

The problem is, therefore, to maintain a constant pressure or tension, whatever may be the number of machines, etc., in the parallels; and it will be seen that the tension which it is required to maintain constant is that at the terminals of the generating machine; it is from these points that the derived circuits feeding the various motors, etc., are supposed to take their origin, and it is the tension at these points which determines the exterior current; this tension, then (scientifically termed, difference of potential), must be so regulated that at any moment it

may be constant, whatever may be the exterior circuit, or whatever variations it may undergo.

The solution of this question has recently become of such urgent importance that a considerable number of plans have been put forward from different quarters, all of which have more or less helped to solve the difficulty.

We will therefore refer to some of these, but we must at once state that the period in which they have all been brought out is really so short, that it is next to impossible to give them in chronological order, or to award the various priorities of conception. The legal points of the question, based on authenticated dates, are of course easily solved, but, as a matter of science, to decide the priority of invention is difficult, owing to the number of claims put forward. Besides, now-a-days scientific researches are, so to speak, democracised. Formerly, inventors were a small and select aristocracy, but now the results seem to arise from a number of small individual researches, rendering them neither less brilliant nor less useful, but somewhat hiding the origin in mystery. We will therefore, instead of following the chronological order, go through them in such a way as to see the successive development of the means employed.

One of the earliest was that of Edison, in which he sought to obtain regularity by modifying the production of the current. There are, of course, three ways of varying the current produced by a machine: the first is to vary the speed, which is ex-

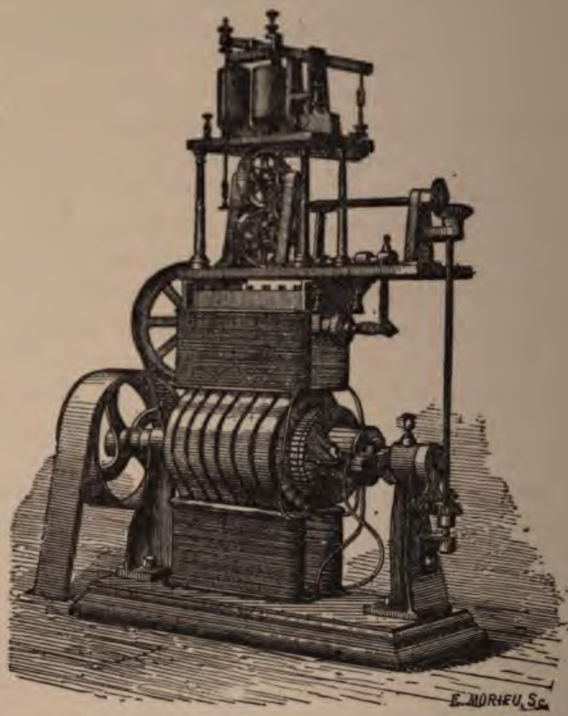
tremely difficult mechanically, and not very practical; the second way is to vary the action of the field magnets by moving them further away from the armature, and it will be seen that this is out of the question; the third way is to vary the current through the field magnets; this is evidently the most convenient method, and the one which has been most generally adopted.

For this there is an essential condition, namely, that the magnets are not excited solely by the useful current of the machine; in fact, it would then be impossible to vary the excitation of the magnets without equally varying the exterior circuit. In the Edison system the field magnets are excited by a shunt from the main circuit. In this accessory circuit is placed a box, and by means of a handle worked by an attendant variable resistances may be thrown in, as may be shown necessary by an indicator, thus always maintaining the proper current according to the demand.

The necessary presence of this attendant is the weak point in this arrangement; it is not automatic, and for an extended service, supplying various and unforeseen wants, this kind of regulation would be insufficient. Mr. Edison has, however, applied his system to a large lighting installation in New York, which is said to work well; but in any case it must be observed that this description of distribution is one of the simplest, including only apparatus all identical, namely, lamps, and has only to supply wants which may in a great measure be foretold.

At the Exhibition was also shown Mr. Maxim's regulator, represented in Fig. 109. This is a mechanical regulator, and consists essentially of a lever continually worked by the machine. This

Fig. 109.



lever, having two cams on it, is suspended between two cog-wheels; if it rises, it touches the upper one, and by means of the cam turns one tooth at each

oscillation; if it falls, the lower wheel is turned. The lever is fixed to the armature of an electro-magnet, through the coils of which passes the current to be regulated; it follows that if the current is too great the armature is attracted and falls, carrying the lever, which then acts on the lower wheel; if the current is too weak the armature, acted on by a spring, is drawn up, thus putting in motion the upper wheel; but for a normal current there is no movement. The cogged wheels thus put in play are not employed to put in resistances as in the Edison arrangement, but they act on the brushes of the machine and alter their position. It will be remembered that in dynamo-electric machines the current is collected by two springs or brushes rubbing on the revolving cylindrical commutator. According to the position of these brushes the current may be collected either at the maximum point or at any other, when there will be less; it will thus be seen that by varying the position of the brushes the current may be varied.

This arrangement is very defective, as will be easily understood. From what has been said about dynamo-electric machines, it will have been understood that the position of the brushes was determined; but if these brushes must be capable of being shifted either way, it follows that their mean position which they occupy normally is not their most advantageous position, and it will be understood how grave a fault this is.

This system has also the great disadvantage of

slowness: theoretically, it ought to act; practically, it did not do so at the Exhibition, and it is very doubtful if it has ever really been used. For a large distribution it would be quite insufficient.

The Lane Fox regulator somewhat resembled the foregoing. Like it, it relied on the action of an electro-magnet, but instead of acting on the brushes as in the Maxim system, it served to introduce or take out artificial resistances in the exciting circuit. These modifications being occasioned by the attraction of a magnet, take place very slowly, and altogether it is not likely to be much used, on account of its being so very slow working.

The Brush system of lighting was very much noticed at the Exhibition, and for some things very rightly so. Without being actually more perfect than others as regards the lamp and the results obtained, it must share with the Jamin candles the honour of having first employed high tensions in the application of electricity to lighting. It has been already stated that M. Gramme had made machines reaching tensions of 300 volts; those of Mr. Brush reached 1000 and even 2000 volts. We have remarked that M. Marcel Deprez, in his experiments on the transmission of force, has also attained and surpassed these tensions. It is interesting to note that an inventor who was not, like Jamin and Deprez, guided by well-thought-out theory, should also have so well understood the necessity for high tensions as to adopt them with boldness.

Our readers will excuse this digression. This was

not the only point of notice in the Brush system, which included also a regulating arrangement, which was, however, very elementary. To vary the exciting current, a shunt was arranged which was opened more or less according to the energy required. It will be seen that by this arrangement any excess was lost, the production remaining uniform. The system also consists of a double regulating arrangement, the one automatic, the other worked by hand, both of which may be criticised from several points. Similarly with those already mentioned, it has not acted well, and is not capable of being extensively used.

Interesting theoretical studies were being at the same time carried on, and to M. Hospitalier is due a complete projected system, apparently satisfying the required conditions. To M. G. Cabanella is also due a special system of distribution. Instead of arranging all the apparatus in parallel as others had done, he put them in series: this has, as we have stated, the objection of necessitating the use of very high tensions, which we think can never be really applied.

One of the most elementary systems of regulation is that of M. Gravier. He reduces the problem to its most simple terms. We have said that the difficulty consisted in the fact of the generating machines having an internal resistance, and that the problem would disappear if this resistance could be done away with. This not being possible, M. Gravier set himself to reduce it. For this he took a number of

machines, and joined them up for quantity, so that they offered the least resistance possible to the current. To reduce it still further, he took care to excite the field magnets separately. This done, he places the machines in circuits as equal as possible, in which he employs very thick leads. It therefore happens that if one circuit is taken out, the remainder, being equal, continue to be supplied as before, and the interior resistance being also very slight, the electric production remains approximately proportional to the exterior resistance. M. Gravier had at the Electric Exhibition an installation on this system; he fed lamps and machines on six different circuits, his generating apparatus being five machines coupled together.

This, however, is not a solution—it is an arrangement which may be useful, a good application of a known principle; but it will be seen that the difficulty is not got over, it is only lessened. It also possesses a great disadvantage, namely, that machines with slight internal resistance necessarily produce electricity of very low tension, and it will therefore be seen that they would in consequence not be adapted to the transport of electricity to a distance. But to distribute usefully, transmission is necessary; this system is then only useful within certain very narrow limits.

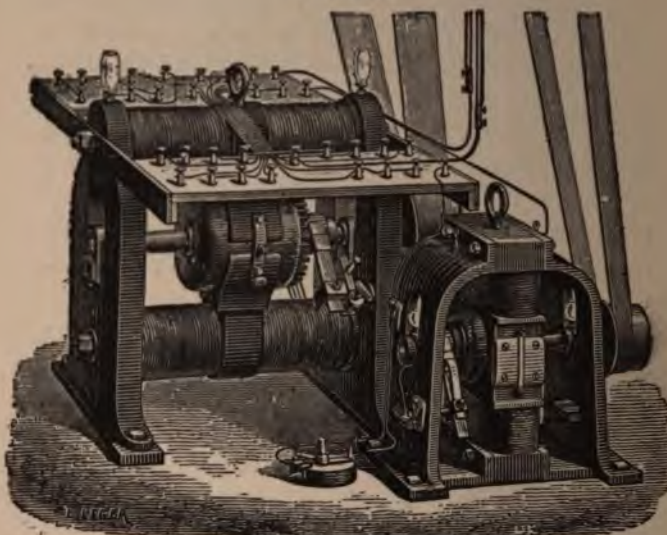
We now come to the solution proposed by M. Marcel Deprez, which is certainly the most important of those which we have yet enumerated, and it has this advantage, that it has been tried. This

took place at the Palais de l'Industrie during the Electrical Exhibition of 1881. The circuit from the generator almost made the round of the building, forming a total lead of about 2 kilometres; at various points chosen without distinction, and only taking into consideration the requirements, parallels were taken off each, feeding various kinds of apparatus working machines for sewing, folding, cutting out, sawing, turning, &c. At one point a number were placed together and formed a small workshop, a branch being taken off for the production of light as well. At the end of the circuit was installed a printing-press driven by a motor also supplied by a branch off the main circuit. All these were started or stopped at will, and each one quite independently of any other, thus forming an example of distribution.

The system merely consisted of two generating machines, one large and one small, working together, and presenting the appearance shown in Fig. 110. That was all; in fact, its great simplicity was its great advantage. No mechanical apparatus was necessary; it was solely dependent on the action of physical forces. M. Deprez discovered that the required result could be arrived at by combining two exciting circuits on the field magnets. For this purpose, on the magnets of the large machine he winds two separate wires; the one being traversed by the current from the small machine, thus giving to the generator a constant magnetisation entirely unconnected with the exterior circuit, and the second

wire, being in the main exterior circuit, is traversed by a variable current, thus adding to the constant magnetisation one varying with the requirements of the exterior circuit. He showed that by proper adjustment this variable magnetisation would be just sufficient to give the necessary increase of electro-

FIG. 110.



motive force as the demand increased. He thus obtained an automatic regulation without the intervention of any exterior apparatus, and satisfying in the most complete manner the required conditions. The Palais de l'Industrie experiment was on a small scale; prudence demands that, before giving a final

opinion, a larger or more practical realisation should be waited for; however, it must be acknowledged that we have here the greatest guarantee for ultimate success.

Closely connected with the above system of compound winding of the field magnets is the Crompton-Kapp principle. These inventors only use one machine, the Bürgin, and on the field magnets they wind two wires, the one being included in the main circuit as in an ordinary series dynamo, and the other being a shunt off that circuit; by this means, with a varying resistance in the exterior circuit, very perfect automatic regulation is obtained. This arrangement was designed for lighting incandescent lamps in multiple arc, and is very largely and successfully used for this purpose; but at Messrs. Crompton's works, at Chelmsford, this machine is also used for the distribution of electric energy of every description. Wires are laid throughout the building having a convenient number of terminals, switches, and safety fuses, placed in the different shops, offices, and the laboratory. To some of these terminals are attached branch circuits (all in parallel arc), which feed Swan lamps for lighting the different parts of the works; other terminals have no permanent connection with branch circuits, but can at any time be coupled up to such branches for the purpose of using the current for some special experimental work. The main circuit is kept charged to a difference of potential of 80 volts by one of these compound wound machines, the combination of main and

shunt wires being so chosen that, no matter what current is taken out of the machine, that current is always delivered at a predetermined and fixed difference of potential. In the present instance, the current taken from the machine varies largely throughout the day, because from the main circuit the following operations are carried on independently of each other, viz. lighting by means of Swan lamps in parallel, testing arc lamps, testing and classifying Swan lamps, charging secondary battery, and transmission of motive power. This last is done in the following manner: each dynamo, after it is finished, and before being sent out, is carefully tested. But before driving it by steam power it is found convenient to run it for some time as a motor, but doing no work, so as to get the journals and the brushes to a proper bearing. The current is also used for polarising dynamos, for the purpose of making sure that the different coils on the field magnets are properly connected up; calibrating volt- and am-meters, testing the fusing point of safety fuses, testing the magnetic properties of different mixtures of cast iron, and a number of other laboratory experiments, which of necessity are constantly going on in a large electric light works. As most of these operations are carried on independently of each other, it often happens that current is required at the same time for many different purposes. Yet there is no difficulty whatever in this, the machine always proving equal to the demand.

Another system of distribution is that proposed by Professors Ayrton and Perry, who advocate the use

of accumulators in the town or centre where the electricity is required, the charging current being supplied from a distance wherever the motive power may be available. They propose the use of electricity of very high tension but of low intensity; by this means, as we have already shown, increasing the economy of working, and not necessitating the use of heavy and expensive conductors. To transform this current into useful proportions, it is to be used to charge a great number of accumulators in series; these are then to be broken up by commutator switches into a number of batteries, each giving a proportionately large current of moderate tension, such as can be made use of for arc or incandescent lamps, motors, etc. This system has never been worked on a large scale, but it has, in common with so many others, the objection of necessitating the use of currents of extremely high tension, which, although necessary for the economical transmission of power to a distance, would in this case be more than usually dangerous to life, as the circuit through the accumulators would of necessity be exposed; and any two persons standing on the ground and simultaneously touching the two extreme accumulators during the charging would be instantaneously killed, owing to the immense difference of potential, which might often amount to many thousands of volts. Of course, when broken up into batteries for use this danger would not exist, as the only current then would be that from the battery itself, being perhaps only 100 to 200 volts.

Another solution of the problem is that put forward recently by Messrs. Goulard and Gibbs. They have shown a small installation on their system at the Westminster Royal Aquarium Electrical Exhibition, where the results obtained certainly appear very satisfactory. The principle employed is that of the induction coil, and consists of a cardboard or wooden cylinder about 50 centimetres high, on which is wound in parallel spirals, and in rows one above the other, a cable, composed of a central copper wire of 4 millimetres diameter, highly insulated. Parallel to this, and completely surrounding it, are six strands of twelve small wires each, individually insulated. The large wire forming the inductor is traversed by the current from an alternating current machine, and the six strands of twelve wires each in which the induced currents are generated have their ends attached to a commutator, so that they may be joined up at will in quantity or in tension. Inside this hollow column is placed a soft-iron cylinder, which can be raised or lowered, by which the current induced in the small wires may be regulated. The instruments shown at the Aquarium consist each of four of these columns arranged in a square, and the ends of all the wires are brought up to the commutator in the middle, so that the whole of the wires may be grouped in tension or in quantity, or some in quantity and some in tension. The practicability of this is shown: one of the instruments has all its wires grouped for quantity, and the current lights twenty-six incandescent lamps. The other generator has two columns

grouped in tension, and lights a Jablochkoff candle, and at the same time one of the remaining columns lights five Swan lamps in multiple arc, and the other drives a small motor. The intensity of the current induced is proportional to that of the primary current, and the tension may be varied according to the way in which the induced wires are coupled up. The inducing wire forms a closed circuit, and of course may traverse any number of these instruments, provided the electromotive force is sufficient to overcome the resistance of the circuit and of the electromotive force generated by the secondary current. The inventors therefore propose to use for the transmission and distribution of power, alternating currents of very high tension, traversing as many of these secondary generators as may be required, they being all arranged in series. From this arrangement they say there can be no danger, since the primary current only traverses a closed metallic circuit, and contact with the body at any part of the circuit would offer too great a resistance to allow the slightest derivation of the current. This system has at present only been shown on this small scale, and therefore it is impossible to speak with certainty as to its action in a practical shape, but the objection to it appears to be in the necessary use of alternating currents of high tension; whether such currents can advantageously be employed on long circuits, where the effects of static charge and induction will have to be taken into account, yet remains to be seen.

This, then, is the present position of the all-important question of the day—the transport and distribution of power by means of electricity. Much, very much has been done, but much yet remains to be accomplished before that almost Utopian state of things arrives, when all the vast powers of nature at present wasted shall be reclaimed and made subservient to human will by being transported through a wire to the centres of civilisation, and there distributed to every one according to each individual requirement. But in the immediate future we may safely prophesy that great progress will be made, and that before many years have elapsed electricity will be almost universally distributed. That will, then, certainly be one of the greatest events of our century, and will constitute a veritable social revolution.

This progress may be summed up in one word: to bring electricity to the home. And electricity is at the same time light, chemical work, and motive power; and that in the smallest quantities that may be desired at the disposal of the consumer, by the simple turning of a key. What advancements may we not look for, then, when many who have now no opportunity of making the experiments necessary to useful discoveries have this wonderful power readily obtainable, when every one has in his own hands, power in its most varied forms, and that at his own home, at his own time, and without being compelled to go to a stuffy workshop for it. The workshop! This word opens to our view other points, for if the

distribution of electricity has for men an immense advantage, it has much more for women. It is for them that the *workshop* is in the highest degree baneful: all know the dangers of this life in common, so profoundly destructive to health and morals. We have already mentioned that the first practical application of the transmission of power was to a factory of sewing machines, thus saving women from a hurtful labour. How much greater will be the advantage when the woman can work her machine, no longer in the workshop, but at home by the hearth of her husband, by the cradle of her infant! It is thus that will be found the true equality of the sexes; it is thus that must be sought the solution of this burning question, the support and the independence of woman. This distribution will prove an efficient remedy for these social difficulties, and if we do not now actually possess it, we may consider it as certain that we soon shall do so.

NOTES.

Note A.—Jacobi's opinions on the future of Electric Motors.—Extract from the Paper presented by him to the Paris Académie des Sciences, in December, 1834.

In the history that we have given on pages 44 and 51 of the researches of Jacobi on the subject of Electro-Motors we have not given the theoretical part of this paper, for it would have appeared too scientific to the readers to whom our volume is addressed. Nevertheless, as, in view of the progress lately accomplished, this question has excited considerable interest, we have thought it right to give it in the form of a note, in order that those not frightened by formulæ may see that this eminent Russian had from the first made a very profound study of the question, and that his hopes were not as vain as might have been thought a little while ago, and as he himself thought a short time after his last attempts. At the time Jacobi presented his paper to the Académie des Sciences, this Institution did not publish an account of its doings, for it was only in 1835, on the proposal of Arago, that was started that most useful publication which, under the title of 'Comptes rendus des Séances de l'Académie des Sciences,' is to-day so appreciated throughout the whole world. Jacobi's paper could not therefore be published by the Académie, but there was in existence a journal

founded by Arnoult, under the title of 'L'Institut,' which took its place, and a résumé of Jacobi's paper is there published in No. 82 (December 3rd, 1834). It is from this that we have borrowed the description given in page 42. Here then are the conclusions with which this résumé ends:

"1. The mechanism of this motor is very simple, compared with that of steam-engines. There are neither cylinder, piston nor valves, &c., the construction of which necessitates great exactitude, and therefore expense, and none of that friction which consumes in pure loss more than half the total work; here there is almost no useless work beyond the friction of the axles in the bearings. Further, this machine gives direct a continuous rotary motion which may be changed into other movements much more easily than when the prime motion is a rectilinear backwards and forwards one. Here also there is no risk of an explosion.

"2. All the motors hitherto employed for the working of machinery are hopelessly subject to the law, that their power is directly proportional to the economical effect or to the cost of production. Here, the intensity of the magnetic force may be increased in three ways: by increasing the voltaic apparatus; by increasing the size of the wires which surround the bars; or by increasing the dimensions of these bars, principally their diameter. The increase of the battery has a limit beyond which the magnetic effect only increases insensibly. The increase of the wire has also a limit, but it is not so restricted. But as for the gain in increasing the dimensions of the iron subjected to the magnetising power of the current, no limit is known. Thus, the new motor does not belong to the category of the motive forces hitherto employed, by the non-proportion between the cost and the effect. If it could still be doubted that even its minimum expense of

working did not in any way correspond with that principle of economy which is always the *sine quâ non* of any mechanical or industrial system, these doubts would be removed when we reflect that magnetism is a force, and and that the electro-magnetic excitation is instantaneously effected. In fact, when the voltaic circuit is closed, the wire, and in consequence the bar on which it is wound, acquires its maximum force in an instant. If some experiments seem to contradict this instantaneousness, there must be some fault in the experiment: either a little oxide on the wire may have retarded the metallic contact, or there must be some other similar disturbing cause foreign to the actual properties of the magnetic force.

"In the same way, if two magnetic systems move one towards the other, their mutual action is always in terms of their distance, so that the total action may be expressed $\int_o^a \mathrm{M}\,ds$. In this integral formula the time or speed only enters into the formula of the universal attraction; it is not affected in any way by the speed with which the two magnetic systems move one towards the other. Therefore, we may get the work $\int_o^a \mathrm{M}\,ds$ done in any time whatever, changing nothing of the nature of the active systems, and without increasing the source of the force. That being settled, and the changing of the poles being made instantaneously, we are able to dispose of a force analogous to gravity, and the expression $\int_o^a \frac{\mathrm{M}\,ds}{a}$ may be compared to the known quantity g."

"The movement of the system will then be an accelerated motion, and cannot become uniform unless some force or resistance is met with which will be expressed in terms of the time or speed. It is with this movement as with that of a body falling from a great height, which

only becomes uniform by the resistance of the air. But we think that such an element, being entirely outside the force, may be reduced at will.

"We shall see that it is not the same with other motors. In fact, if we establish an integral of the same form $\int_o^a \mathrm{P}\,d\,s$, for the work we can get from it, we may easily suppose that the point where the force P is applied has no other movement than that which is given to it by the motive force, which properly speaking is not a force, but, like muscular power, water, wind and vapour, a system of material points animated by forces. As soon as the point of application takes a normal movement, its speed must enter into the formula $\int_o^a \mathrm{P}\,d\,s$, and combines in it with the time which must elapse to produce the intensity which the maintaining of this new speed demands. From this often result very complicated phenomena, as for instance in locomotive steam-engines.

"To establish a precise difference between ordinary motors and the new magnetic agent, we may say that with the former the accelerated movement becomes uniform, not by the increase of the resistance, but because the action of the force on the point of application is weakened; whilst with the latter, if the movement can be made uniform, it is in consequence of some extraneous cause altogether independent of the principle of the force. Magnetic force may then be compared to gravity by supposing that we have at our disposal an infinite height; it acts in all directions without meeting a fixed obstacle, whilst gravity does so at the surface of the earth.

"In short, to enunciate in one word the technical importance of the new agent, we may say—in electric machines speed costs nothing."

Note B.—Some Details of Trouvé's Battery, as used in his Electric Boat.

Each element of this battery is composed of a plate of zinc placed between two carbons. The dimensions are as follows:—

Total height	·24 metre.
Width	·16 „
Thickness	·005 to ·008 metre.

The immersed surface is about ·16 metre square.

The carbons are electro-coppered at the upper part, which considerably diminishes the resistance of the battery, gives a good surface for the contacts, and consolidates the carbon, always rather a brittle substance. The zinc plates, heavily amalgamated, have on their upper part a notch, into which is fitted the metal couplings covered with india-rubber, which supports the elements. This allows of ready removal, either for amalgamation or for any other purpose. The exciting liquid contains much more bichromate of potash than ordinary solutions, and it was also found necessary to increase the quantity of sulphuric acid to as much as a fifth, or even a fourth, of the total weight of water. As much as 250 grammes of bichromate per litre of water have in this manner been dissolved, and the constants of each element are, according to M. d'Arsonval:—

Electromotive force E	1·9 volt.
Internal resistance r	·08 ohm.
Intensity at moment of insertion ..	118 ampères.

On joining up a battery of six cells of this description

with a one-bobbin Trouvé motor, M. d'Arsonval gives the following as the result:—

Work in the brake ..	3·75 kilogrammetres per second.
Current	20 ampères.
Zinc expended per hour	144 grammes.

Whence it appears that each gramme of zinc gives by this means 94 kilogrammetres of force. If we add to this 20 per cent. for the work absorbed in the double transmission by gearing and endless chain (the brake not being able to be applied direct on the axis of the motor), we have an effective work of 112 kilogrammetres per gramme of zinc consumed; and it is said that, with motors having several bobbins, this return has been exceeded.

It is also said that this battery, when used in conjunction with a Gramme machine, has been made to furnish for three consecutive hours a force of 14 kilogrammetres per second, and the following is a table of experiments undertaken by M. Trouvé:—

Motor.	Weight of Motor.	Work Measured at Brake.	Number of Cells.	Kilogrammetres per Hour.	Work per Gramme of Zinc.	
	klgmes.	klg.			kgm.	kgm.
1 bobbin	3·300	3·75	6	13·500	93·75	112·75
2 bobbins	5	8	12	28·800	100	120
4 "	10	20	24	72·000	125	150
8 "	20	56	48	201·600	175	206

NOTE C.—ON THE ELECTRIC RETURN.—COUNT DU MONCEL'S REPLY TO CERTAIN CRITICISMS ON DEPREZ'S EXPERIMENTS BETWEEN MIESBACH AND MUNICH.

The inaccurate manner in which my communication to the Académie with respect to these experiments has been received, compels me to explain myself more fully than I have hitherto done on the subject of what is called the

electric return. It is for want of exactly understanding this term that many persons have believed that there was a regrettable contradiction between the figure of the electric return as at first given by M. Deprez and the figure of the mechanical return afterwards obtained by the Electrotechnical Commission.

The return of an electromotive machine in regard to another which puts it in motion is expressed by the proportion of the useful mechanical work developed by the second to the work absorbed by the first. But the work may be estimated in two different ways: either by mechanically applying a dynamometer to the generating machine and a Prony brake or some other similar apparatus to the second; or by electrically measuring the intensity of the current traversing the two machines, as also the electromotive forces, the one direct and the other inverse, developed by the two machines. In the second case, the mechanical work absorbed by the first machine and that returned by the second may be ascertained by the electric measurements taken, by applying certain fundamental dynamic theorems which I will here briefly recapitulate. But, before going further, it is necessary to observe that the return calculated from this second method is necessarily higher than that obtained by direct mechanical measurement, for it is nothing less than the expression of what the mechanical return would be if the machines were perfect, i.e. exempt from friction, instability, and even certain electric imperfections which can only be completely eliminated if the armature ring were composed of an infinite number of sections infinitely small. These last causes of loss are generally very small, and do not exceed 3 or 4 per cent.

Joule's law enables us to calculate easily the mechanical work developed in the form of heat in an inert circuit, that is to say, in which there are neither mechanical nor

chemical actions. This quantity of work has for expression one of the three forms, $R I^2$, $\frac{E^2}{R}$, or $E I$. The first is where the resistance R and the intensity of the current I are known, the second when the electromotive force E and the resistance R, and the last when the electromotive force E and the intensity I are respectively known. The two last expressions are easily deduced from the first (which was obtained by experiment by Joule) by combining it with Ohm's law.

It must be observed that the numbers obtained by these expressions represent kilogrammetres per second when E, I, and R are respectively expressed in volts, ampères, and ohms, and when each is divided by the number $g = 9{\cdot}81$ metres, which represents the acceleration due to gravity. If it is required to know the number of calorics developed in one second by the passage of a current, the number of kilogrammetres found must be divided by the mechanical equivalent of heat, or 425. The quantity of mechanical work (expressed in kilogrammetres per second) liberated in an inert circuit under the form of heat, by the passage of an electric current, is represented indifferently by one of the expressions $\frac{R I^2}{g}$, $\frac{E^2}{g R}$, $\frac{E I}{g}$.

Let us now consider the case where the circuit instead of being inert, as we have supposed, contains a perfect electric motor (i. e. one based on the principle first applied by Pacinotti), free from friction and vibration, and the axis of which is provided with a brake enabling the total work developed to be measured when the motor turns. The total energy developed by the source of electricity then appears in the whole circuit in two different forms: heat and work. Since the intensity of the current being the same at all points of the circuit, whatever may be the nature of the phenomena taking place therein (Ohm's law

verified by Faraday[1], and the resistance of a metallic circuit being under proper conditions independent of its state of repose or of motion, as also of the electromotive forces of which it may be the seat,* the quantity of heat developed in the whole circuit is always represented by $\frac{RI^2}{g}$.

Again, the total quantity of work or energy generated by the source and expended in the total circuit, either in the form of heat or in the form of work, is in every case represented in kilogrammetres per second by $\frac{EI}{g}$. Numerous demonstrations have been given of this fundamental theory, and it is not necessary to repeat them here, but we will show how it may be directly deduced from the principle of the conservation of energy, and from the law of Faraday. Take a battery of n elements, having each an electromotive force taken as unity and producing a current of intensity I. According to the law of Faraday, the quantity of zinc dissolved in each element in unit time is proportional to I, and the *total* quantity of zinc dissolved in the n elements will consequently be proportional to n I, that is to say, to E I. But to this quantity of zinc dissolved corresponds a certain number of calories, i. e. a quantity of energy perfectly determined. We may thus say that the total quantity of energy produced by a source of electricity in unit time is proportional to E I, and is in reality measured by $\frac{EI}{g}$, as we

* Some have thought that certain effects observed in the movable parts of machines in motion were caused by a real increase of the resistance of the machine: but a closer study showed that this was accounted for by secondary effects, the electromotive force of extra currents having nothing to do with the resistance of the circuit.

have said above, when the British Association units are adopted.

Let us now call T the mechanical work produced by the motor expressed in kilogrammetres per second: the total energy developed by the source equals the sum of the partial energies developed in the whole circuit, and we shall have the equation $\frac{\mathrm{E\,I}}{g} = \frac{\mathrm{R\,I}^2}{g} + \mathrm{T}$; whence we have $\mathrm{T} = \frac{\mathrm{I}\,(\mathrm{E} - \mathrm{R\,I})}{g}$.

To understand the second term of this equation, let us bring the expression $\mathrm{E} - \mathrm{R\,I}$ into its simpler form, and for that let us remark that in the fundamental equation representing Ohm's law $\mathrm{I} = \frac{\mathrm{E}}{\mathrm{R}}$, it is expressly understood that E represents the algebraic sum of the positive electromotive forces and the negative electromotive forces (if there be any) in the circuit, so that if we represent the first by E and the second by e, the equation becomes $\mathrm{I} = \frac{\mathrm{E} - e}{\mathrm{R}}$, whence $e = \mathrm{E} - \mathrm{R\,I}$. The expression $\mathrm{E} - \mathrm{R\,I}$ then always represents a negative electromotive force, and we may conclude that when a motor furnishes work it necessarily generates a contrary electromotive force, which is exactly what is proved by experiment.

Using this form for the term $\mathrm{E} - \mathrm{R\,I}$, the equation of work becomes $\mathrm{T} = \frac{e\,\mathrm{I}}{g}$, or remembering that $\mathrm{I} = \frac{\mathrm{E} - e}{\mathrm{R}}$ $\mathrm{T} = \frac{e\,(\mathrm{E} - e)}{g\,\mathrm{R}}$, so that the total energy developed by the source becomes $\mathrm{T} = \frac{\mathrm{E\,I}}{g} = \frac{\mathrm{E}\,(\mathrm{E} - e)}{g\,\mathrm{R}}$ and the work lost in the form of heat $\frac{\mathrm{R\,I}^2}{g}$ or $\frac{\mathrm{R}}{g}\left(\frac{\mathrm{E} - e}{\mathrm{R}}\right)^2$ or $\frac{(\mathrm{E} - e)^2}{g\,\mathrm{R}}$.

We will tabulate these results as follows:—

Total energy in kilogrammetres per second.	Spent by the source	$\dfrac{\mathrm{E\,I}}{g} = \dfrac{\mathrm{E\,(E}-e)}{g\,\mathrm{R}}$
	Recovered in the form of work in the motor	$\dfrac{e\,\mathrm{I}}{g} = \dfrac{e\,(\mathrm{E}-e)}{g\,\mathrm{R}}$
	Lost in the circuit in the form of heat	$\dfrac{\mathrm{R\,I^2}}{g} = \dfrac{(\mathrm{E}-e)^2}{g\,\mathrm{R}}$

These expressions constitute what may be called the fundamental equations of the theory of the transport of force.

They are, however, strictly applicable only to motors electrically perfect, i.e. to those in which the electromotive force undergoes no variation throughout a complete revolution.

This ideal is realised by instruments which serve to demonstrate the rotation of a movable circuit by a magnet acting as the axis of this circuit. Motors founded on the principle of Pacinotti approach the nearer to this perfection the greater the number of sections in the ring; but, as we said above, they may be considered as being at present so near to absolute perfection, that there is little hope of improving them in this respect. The dynamometric experiments which these machines have undergone of late years, have proved in fact that the expression $\dfrac{\mathrm{E\,I}}{g}$ represents about ·95 of the mechanical work applied to the pulley after deductions are made for the work expended in overcoming friction; that is to say, that if the total work applied to the pulley is represented by 100, and the work absorbed by friction by 10, the product $\dfrac{\mathrm{E\,I}}{g}$ may reach $\dfrac{95}{100}$ of the remaining work (100 − 10) absorbed in work purely electric, or 85·5. The difference 90 − 85·5

then represents the loss due to electric imperfections, which would exist even in a motor free from all friction, which amounts, as I said at the beginning of this article, to 4 or 5 per cent.

The fundamental equations enable us to calculate immediately the value of the economical return, i. e. the proportion of mechanical work recovered in the motor to that absorbed in the generator. For that it suffices to divide the first expression by the second. We therefore have, calling k this economic return,

$$k = \frac{e\,\mathrm{I}}{g} \div \frac{\mathrm{E\,I}}{g} = \frac{e}{\mathrm{E}}.$$

But this expression is *independent of the resistance*, and it may therefore be concluded that the economic return only depends upon the proportion between the counter electromotive force of the receiver and the electromotive force of the generator. This is what M. Deprez tersely expressed when he said, "the return is independent of the distance." But if the economic return is independent of the resistance, the *absolute work* * is not in the same case, and it is this which some who have discussed the experiments of M. Duprez have affected to call the return, being ignorant of the fact that this term has always had in mechanics a perfectly defined signification long before it was thought of applying it to electromotors.

In order to see the influence of resistance in the circuit on the absolute work, we will introduce into the above equations the value of the economic return k which it is desired to obtain. From the equation $k = \frac{e}{\mathrm{E}}$ we have

* To maintain constant the work transmitted, whatever may be the resistance, M. Marcel Deprez has shown that the electromotive force of the source must be increased proportionately to the square root of the resistance.

$e = k\,E$, and making use of this value of e in the preceding equations, they become:—

Work absorbed by the generator .. $\dfrac{E^2(1-k)}{g\,R}$

Work recovered in the motor .. $\dfrac{E^2k(1-k)}{g\,R}$

Work lost in the form of heat .. $\dfrac{E^2(1-k)^2}{g\,R}$

But in this form they lend themselves to discussion. The second shows immediately that if we suppose the electromotive force E of the generator as given, the work recovered in the receiver may be obtained by giving the economic return two different values complementary one of the other, such as $\frac{2}{10}$ and $\frac{8}{10}$, or $\frac{3}{10}$ and $\frac{7}{10}$, or $\frac{4}{10}$ and $\frac{6}{10}$.

Thus the absolute work of the receiver may be the same in two different experiments, although the economic return has very dissimilar values.

We shall see that these differences result from the weight put on the brake applied to the machine. According as the weight on the brake is great or small, so the speed of the receiver is low or high, but the work per second, i. e. the product of the resisting effort of the brake, and the speed at the point of application of this effort, may be the same. This work also may be nil in two cases, when $k = 0$, and when $k = 1$.

The first of these is when the brake is so heavily loaded as to completely prevent the receiver from turning, and the second when it is, on the other hand, completely taken off. There is therefore a value for the economic return, for which the useful work of the receiver is the greatest possible. The sum of the two expressions k and

$1 - k$ being constant, this maximum is reached when they are equal: that is to say, when $k = \frac{1}{2}$. This further gives the result $\frac{E^2}{g R}(1 - 2k)$ of the second term of the second equation. The useful work recovered therefore becomes $\frac{E^2}{4 g R}$, and the work spent in the generator $\frac{E^2}{2 g R}$. If the receiver is entirely prevented from turning we should have $k = 0$, and the work absorbed by the generator then become the greatest possible, or $\frac{E^2}{g R}$, the identical value which would be obtained by Joule's law for an inert circuit. We see that the maximum mechanical work developed by the receiver corresponds to the economic return being equal to $\frac{1}{2}$, and that when the economic return is varied between 1 and zero the work spent in the generator constantly increases from zero to $\frac{E^2}{g R}$, although the electromotive force remains constant.

These considerations, although very simple, appear somewhat delicate and complicated at first, and it is from not having well comprehended them that many have lately written a vast amount of inaccurate criticisms on the transport of force. To cite only one example, one of the most common errors consists in the belief that the economic return can never exceed 50 per cent., because it reaches this value when the work developed by the receiver is the greatest possible in absolute value.

All the functions of generator and receiver become perfectly clear when we take as a starting point the weight on the brake on the receiver, as M. Deprez has done in his latest theoretical studies on the transport of force. He has, in fact, shown that this single element is

sufficient to completely determine the speed, and in consequence the absolute work of the receiver, its counter electromotive force, the economic return, and the intensity of the current, provided that certain elements in the construction of the machines and the resistance of the circuit are known.

He was thus enabled to obtain formulas remarkable for their simplicity and for the small number of variable elements contained therein, and in which electrical symbols do not appear, but are replaced by a new element to which M. Deprez has given the name of "Cost of the static effort" (Prix de l'effort statique). This depends solely upon the construction of the machine, and has no reference to its internal resistance. I would refer those who wish to go further into this question to 'La Lumière Electrique' for November 4th, 1882; but I think it well to describe here the fundamental experiment on which this new theory is based, which experiment M. Deprez very recently repeated in my presence.

On the axis of any receiver, Gramme or Hefner-Alteneck, is fixed an automatic regulating dynamometer brake, that is to say, one maintaining strictly constant the tangential effort applied to the pulley of the brake, whatever may be the variation in the friction. A current is then sent through the receiver, taking care to have an intensity galvanometer or am-meter in the circuit. Another galvanometer, which must have a very high resistance, is placed in derivation at the terminals of the generator in order to ascertain the difference of potential between these terminals. These arrangements being made, the generator is revolved at a gradually increasing speed, and it will be seen that as long as the receiver does not move, the two galvanometers are progressively deflected proportionately and continuously, showing that the electromotive force of the generator and the intensity of the current generated

are proportionately increased. But from the moment when the receiver begins to move, the needle of the intensity galvanometer remains steadily fixed at the then deflection, whatever may be the speed of the generator, while the needle of the galvanometer in derivation shows that the electromotive force increases more and more with the speed of the generator. The speed of the receiver is in the same case, which in the experiment I witnessed varied between zero and 32 revolutions per second, the intensity of the current not varying more than $\frac{1}{30}$ of its proper value.

The same result may be obtained if the experiment is made in another manner, namely, by adding to or decreasing the resistance in the circuit when the intensity of the current remains constant. Whatever we may do, therefore, as long as the receiving machine moves at all, it is impossible to vary the current as long as the weight on the brake is not altered. Any increase in the electromotive force of the generator, or, what comes to the same thing, any decrease in the resistance of the circuit, has only the effect of increasing the speed of the receiver. But on the other hand, if the weight on the brake is changed, the current necessary to keep the receiver in motion with this weight changes also, at the same time remaining independent of the speed of the receiver. The necessary conclusion with regard to this important experiment is, according to M. Deprez, that the effort developed between the fixed and movable parts of a dynamo-electric machine, when it is traversed by a current, is independent of the speed and direction of the ring, and only depends on the intensity of the current. This principle was, moreover, suggested by Mr. Pollard about three years ago.

M. Marcel Deprez has, by means of this single law, entirely reconstructed the theory of the transport of force, rendering it so simple that it will not be out of

place to give here an example of its application to a particular case, since it has already been made public.

Suppose two precisely similar dynamos, the one being generator and the other receiver, placed on a circuit of any resistance; the receiver being fitted with a brake with a known weight on it, and the generator being driven at a gradually increasing speed. In virtue of the above law, the current will become constant as soon as the receiver begins to revolve, and the tangential effort developed on the pulley of the generator will be equal to that applied to the pulley of the receiver, by reason of the independence of the mechanical action of the current (which is the same at all points of the circuit), in respect of the speed or direction of the movement of the armature. But the two rings having similar dimensions and being subject to similar tangential efforts, the return is expressed by the proportion between their respective speeds. But it has long been indisputably established that in a magneto-electric machine the electromotive force is proportional to the tangential speed of the pulley, and the intensity of the magnetic field, and the two machines being similar and traversed by the same current, their magnetic fields are equal; therefore the electromotive forces respectively developed by the receiver and generator are proportional to the speeds of the armatures. Consequently, calling the corresponding electromotive forces and speeds of the two machines e, E, and v, V, respectively, and k the return, we shall have $\frac{e}{E} = \frac{v}{V} = k.$

We thus come back to the value $\frac{e}{E}$, which we have already obtained for the economic return by quite a different method.

With regard to the experiments of M. Marcel Deprez, when it is remembered that before this experiment the

boldest enterprise in this direction was with a 4 millimetre copper wire, 6400 metres long, with a resistance of 8·4 ohms very carefully insulated throughout its entire length, and that M. Deprez elected to make use of an iron telegraph wire exposed to the rain, 114,000 metres in length and with a resistance of 950 ohms, and that notwithstanding these enormous differences in the conditions of the two experiments, the same industrial return was obtained, namely, 50 per cent., it will be conceded that the Miesbach-Munich experiment was of the utmost importance in the history of the transport of force. The obstinacy with which the adversaries of M. Deprez, no longer being able to raise doubts as to the reality of the experiment which they prophesied beforehand would cover him with ridicule, now do all they can to make light of and detract from the results by disputing the mechanical return, is the completest proof that could be desired. Carried away by their spirit of criticism, they endeavour to destroy every point of the new theory of the transport of force; and quoting figures entirely without proofs, they triumphantly calculate that theoretically the return should be less than that actually arrived at by means of brake and dynamometer!

When M. Marcel Deprez, in his communication to the "Académie," gave for the value of the return 60 per cent., he took care to say that this return was measured (the two machines being identical) by the proportion between their speeds (2000 and 1200 revolutions), deducting all passive resistances, and this showed that it was the theoretical return $\frac{e}{E}$. His communication was addressed to scientific men, and there was no necessity to explain himself further, because he knew that the special public to whom it was addressed would not misunderstand it and

would know how to distinguish between the return $\frac{e}{E}$ or $\frac{v}{V}$ and the industrial return.

He could besides not give the direct electrical measurements (electromotive force and current), because he had not the instruments necessary to obtain them, nor dynamometrical measurements as to the generator. He was therefore obliged to wait for the Electro-Technical Commission to make their experiments.

In 'La Lumière Electrique' he published a detailed account of the circumstances attending the experiments, and I will only add one particular given to me by M. Deprez himself authorising me to publish it, making a reserve as to the absolute exactitude of the figures, which he was only able to obtain verbally from the members of the Commission, who were themselves unable to obtain the figures for all the experiments.

The difference of potential measured direct between the terminals of the Munich machine, revolving at between 720 and 760 a minute, was about 830 volts, and the current as measured at Miesbach was ·4 ampère. But from the experiments of Professor Kittler with a battery of 100 Meidinger cells (having a total E. M. F. of 105 volts), after 14 days' rain and using the earth as return, it appeared that a current having at Munich an intensity of ·0692 ampère was still, on its arrival at Miesbach, equal to ·0674, or ·974 of its original intensity. It may be taken, then, that the current had practically the same intensity at Miesbach as at Munich, namely, ·4 ampère;* but the resistance of the machine at Munich was 475

* According to the official figures subsequently published, it appears that this intensity was ·5 ampère instead of 4. From this it results that the efficiency above estimated of ·46 only reached, according to the report of the committee, ·389.

ohms. These numbers enable us to calculate the electromotive force and the theoretical value of the work which should be produced by the machine at Munich. We have then

$$e = 830 - (\cdot 4 \times 475) = 640 \text{ volts}, \frac{e\,\mathrm{I}}{g} = 25\cdot 6 \text{ kilogrammetres.}$$

But the work indicated by the brake was $\frac{1\cdot 5 \times 740}{60} =$ 18·5 kilogrammetres; the efficiency of the receiver was then about $\frac{1\cdot 85}{2\cdot 56} = \cdot 72$. Further, the resistance of the line was 950 ohms, that of the generator at Miesbach 470 ohms; and these figures easily enable the electromotive force of the Miesbach machine to be shown, namely, $830 + (\cdot 4 \times 1420) = 1400$ volts.

The work absorbed was theoretically $\frac{1400 \times \cdot 4}{9\cdot 81} = 56$ kilogrammetres per second; and supposing that its efficiency was also ·72, it will be found that a mechanical work of about 80 kilogrammetres should have been absorbed. The electric return measured by the proportion between the electromotive forces would therefore be $\frac{640}{1400} = \cdot 46$, and measuring it by the proportion between the speeds * (the Miesbach machine making 1600 revolutions per minute), we have $\frac{730}{1600} = \cdot 455$. Too great importance need not be attached to the remarkable coin-

* In the experiment made on the 26th September by M. Sarcia, the speed of the generator was 2200 revolutions per minute, that of the receiver 1508, and the work on the break reached 37·5. These numbers were checked by Mr. Tatterer, who was attached to the technical service of the Exhibition.

cidence of these two figures: they might have largely differed, and still have confirmed the expression of the electric return. It may be added that for a week the receiver worked a centrifugal pump running at 900 revolutions per minute (the pulleys being the same size), and fed a pretty fountain nearly 3 metres in height.

After several hours' consecutive running the two machines showed no appreciable rise in temperature, which, considering their enormous internal resistance, shows plainly that the intensity of the current was very slight, as well as the quantity of energy lost in the form of heat.

I think I have abundantly shown that the success of the bold experiment undertaken by M. Marcel Deprez has fully confirmed the calculations and the theoretical views of this scientist, and that the incompatibility which his opponents wished to establish between the electric return and the mechanical return does not exist. In concluding, I must express the regret that the experiments of the Commission were not able to be undertaken under the same conditions as the first experiment made by M. Sarcia, when the useful work reached ½ horse-power, and the return would have reached a higher figure. M. Deprez has, with many other details given in his letter of the 11th of November last, stated the causes which prevented the Commission from working under similar conditions.

TH. DU MONCEL.

Note D.—On the Characteristic Curve of Dynamo-electric Machines.

Since the application of dynamo machines has become so common, the different effects that they realise, and the characteristics and properties that they possess, have been much studied; and M. Deprez has found a very simple method of representing by a curve these different characters, and by simple graphic lines the different effects that a machine will give. To this curve has been given the name "*Characteristic*."

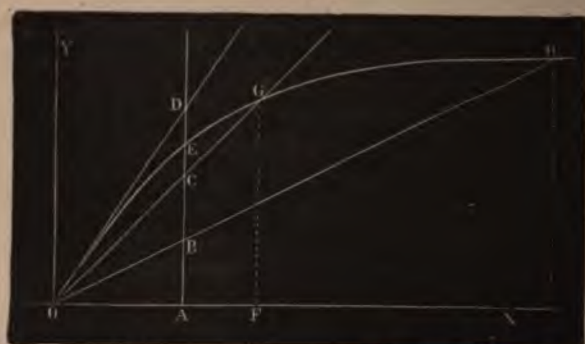
To obtain it, currents of known intensity are sent from an independent source through the field-magnet coils, the armature being revolved at speeds also known. For each intensity of current thus sent through the inducing circuit, the electromotive forces developed in the armature are measured, and are successively plotted off along a vertical line forming the ordinates of the required curve, at the same time marking off the intensities as abscissæ on the perpendicular line. Then by describing a line through the different intersections of the vertical and perpendicular lines, the characteristic curve of the machine experimented upon is obtained.

The form of this curve depends upon the construction of the machine, its dimensions, and the proportion between its various parts; it represents its actions and clearly shows the properties of the apparatus, hence the name which has been given to it. It even enables a graphic solution of the questions which may arise in the use of such machines to be readily obtained, and assists in the explanation of several interesting phenomena. Thus, for example, when the curve for a Gramme machine, as shown in Fig. 111, is studied, it is seen that the electromotive force developed increases rapidly at first, becoming less

and less rapid, and ends by remaining stationary towards H, the curve tending to become parallel to the horizontal line; this shows that the magnetization of the soft iron does not increase indefinitely, and that there is a point of saturation which, it is true, is not completely attained, but towards which it more and more tends.

As the intensity of a current is proportional at the same time to the electromotive force and the resistance, it will be easily understood that, knowing by the preceding curve the electromotive force and the intensity of

Fig. 111.



the current at the different points of the curve, the resistance of the circuit R corresponding to an intensity and electromotive force given may be readily deduced; for, if their proportion exactly represents this resistance, as is given by Ohm's formula, $R = \frac{E}{I}$, and as the proportion $\frac{E}{I}$ represents the two sides of a right-angled triangle, it then becomes equal to the tangent of the angle formed by the line of abscissæ O X with the line G O, for example, which joins O with the point G of the curve. If this angle is 45° the tangent becomes equal to 1, repre-

senting the ratio of unit E. M. F. to unit intensity, i. e. the ohm, or unit resistance, and it may be made use of to form a graduated scale of resistances.

Let us now examine what happens when we increase or diminish the resistance represented, as we have said, by the tangent of the angle corresponding to the different points of the curve. It will be seen that, for points in the part almost parallel with the line of abscissæ as H, the resistance of the circuit becomes less and less, and that on the other hand it becomes greater for points on the opposite side, which consequently shows a progressive increase of the electric intensity in the one case, and a rapid decrease of this intensity in the other; a point will even be reached when there is no longer any current transmitted: this will be when the line O D limiting the tangent will itself be tangent to the curve at its origin O. This shows that for dynamo-electric machines there is a resistance for which the excitation is nil, and ceases to act.

The characteristic curve of a dynamo is essentially connected with the speed V of the armature and with the number of turns, t, of the coil surrounding it; for the electromotive force developed is, as experiment proves, proportional to these two quantities. Consequently, to obtain the characteristic curve of a machine in which we vary the speed and the number of turns on the ring, the ordinates of the curve must be multiplied by $\frac{V'}{V}$ or $\frac{t'}{t}$, which will give the electromotive force; and we may also ascertain the resistance of the circuit as well as the intensity of the current by means of a simple geometrical figure which Marcel Deprez has given, with many others relating to this question in his great work on characteristics, published in "La Lumière Electrique" for December 3rd, 1881, to which we would refer the reader.

In a series of other articles, published in vols. vi. and vii. of "La Lumière Electrique," M. Deprez also gives the curves for the principal dynamo-electric machines in use, exemplified in different manners and with different speeds. These will be found very valuable to those who are concerned in the question of electromotors. They will be found vol. vi. p. 364; vol. vii. pp. 114, 160, 219, 580, 599.

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